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NOISE FROM INDUSTRIAL PLANTS

DECEMBER 31, 1971

U.S. Environmental Protection Agency
Washington, D.C. 20460

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NOISE FROM INDUSTRIAL PLANTS

DECEMBER 31, 1971

Prepared by

L. S. GOODFRIEND ASSOCIATES
under
CONTRACT 68-04-0044

for the

U.S. Environmental Protection Agency
Office of Noise Abatement and Control
Washington, D.C. 20460

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FOREWORD

The objectives of this study included the following:

(1) To identify as many sources of noise as possible in five typical industrial plants. The plants selected for the field survey included the following types:

   (a) Glass Manufacturing Plant
   (b) Oil Refinery
   (c) Power Plant
   (d) Automobile Assembly Plant
   (e) Can Manufacturing Plant

(2) To measure the in-plant source noise levels.

(3) To measure environmental noise in the communities adjacent to the above industrial plants.

(4) To determine the community noise exposure and impact due to industrial plant noise.

(5) To identify the human-related problems associated with the noise sources.

(6) To identify the contributory reasons for initiating noise abatement programs and current attitudes toward noise legislation.

(7) To identify the groups or organizations responsible for initiation of the noise abatement programs.

(8) To assess the state-of-the-art for application of noise abatement technology to the noise sources identified above.

1. SUMMARY

Industrial plant activity in the United States ranges from the very small - one man garage operation - to the very large - multimillion dollar, multiproduct operation. The U.S. Bureau of the Census in Statistical Abstract of the United States (1971) reports that the total number of industrial establishments for the year 1971 was 311,000 and the plants employ approximately 14,356,000 production workers.

The types of industrial plants vary greatly in scope, but have been categorized for th~~is~~e study into four basic types:

(1) Product fabrication plants,
(2) Assembly plants,
(3) Power generating stations, and
(4) Process plants.

The product fabrication plant category, due to the broad range of activities, was further subdivided into metal fabricating plants and molding plants.

A representative industrial plant was selected from each category for th~~is~~e study. The plants selected and the number of each type in the United States are presented as follows:

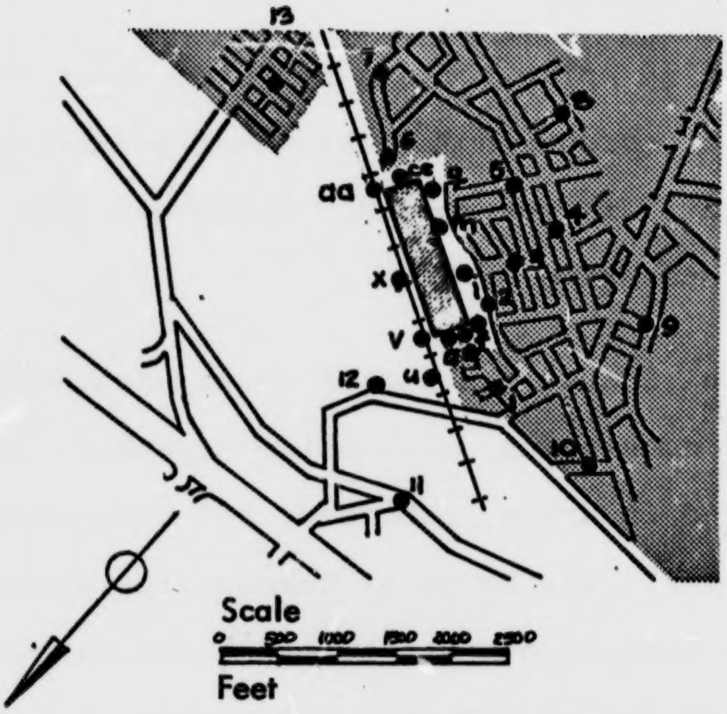
Category	Survey Plant	No. of Plants in U.S.
Molding	Glass Manufacturing	305
Process	Oil Refinery	438
Power	Power Plant	3429
Assembly	Automobile Assembly Plant	98
Metal Fabrication	Can Manufacturing	300

Note that the number of plants in the country represented by the plants surveyed consists of only 1.5 percent of the total of 311,000 industrial plants in the United States. This is considered a small sample.

Industrial plants, though clustered near large urban centers needed for manpower pools, may also be found located in suburban and rural communities. Site selection parameters for new facilities are complex and beyond the scope of this report. Noise is a parameter oftentimes considered. An excellent example is a typical public utility power plant where a total pollution impact study (including noise) is prepared prior to final site selection. The power plant corporate management, sensitive to community response, authorize noise surveys prior to plant construction and insure, through noise abatement controls, that community ambients are not markedly increased when the plant is in full operation.

Typical industrial plants (glass manufacturing, oil refinery, power generating, automobile assembly, and can manufacturing) located in urban, suburban, and rural communities were surveyed. The noise at communities adjacent to these industrial plants was recorded for five minute sampling periods during two days and nights when the plants were operating normally. During appropriate weekend periods, noise levels (A-weighted) were observed at the plant boundary and in the communities at the locations chosen for the recordings. The ambient noise level, L_{90}, is defined as the level of noise exceeded 90 percent of the time during the sampling period, while the intrusive noise level, L_{10}, is that level of noise exceeded only 10 percent of the time during the sampling period.

The weekday, weeknight, and weekend average ambient noise levels in the community and at the plant property line are presented together with maps of each area as Figures 1-1 through 1-5.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Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Weekend	46	54	45	39	41	43	-	-	48	41	41	51	43
Weekday	50	59	44	42	42	40	44	40	41	44	39	53	43
Weeknight	52	61	46	40	43	45	43	40	41	41	42	49	42

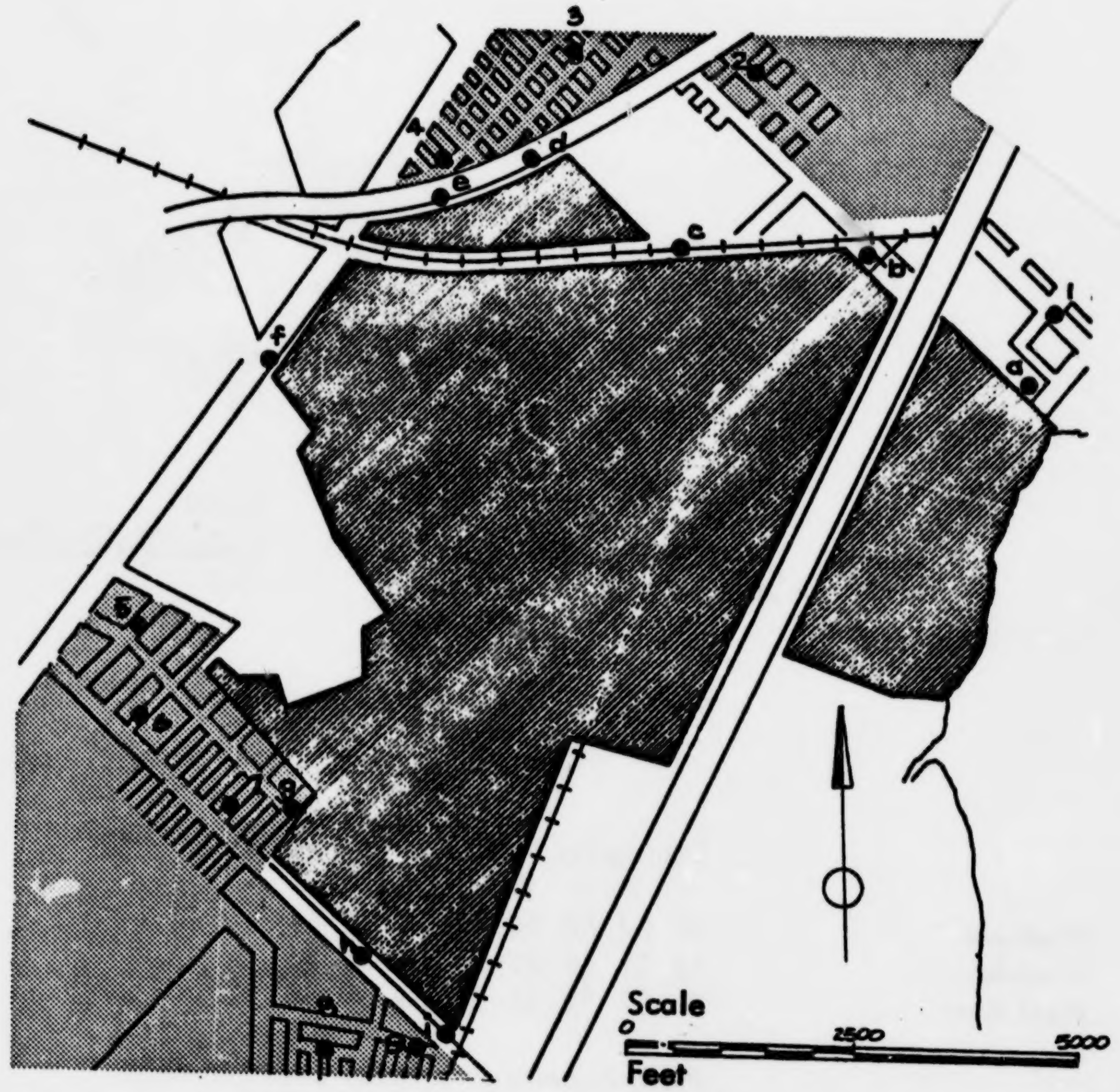
Plant Property Line Noise Levels in dB(A)

	a	e	f	j	m	q	cc	aa	x	v	u
Weekend	50	62	59	68	55	41	44	40	60	65	52
Weekday	49	64	61	68	59	49	50	49	66	68	55
Weeknight	51	64	63	69	58	48	41	46	61	65	54

Key

■	Industrial Noise Source
▨	Residential Area
+–+–+–+	Railroad Track
═	Highway
●	Measurement Location

Figure 1-1. Glass Manufacturing Plant Community



Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8	9
Weekend	59	49	52	55	50	50	50	48	51
Weekday	63	52	50	56	48	51	54	47	50
Weeknight	60	51	51	50	47	49	59	47	49

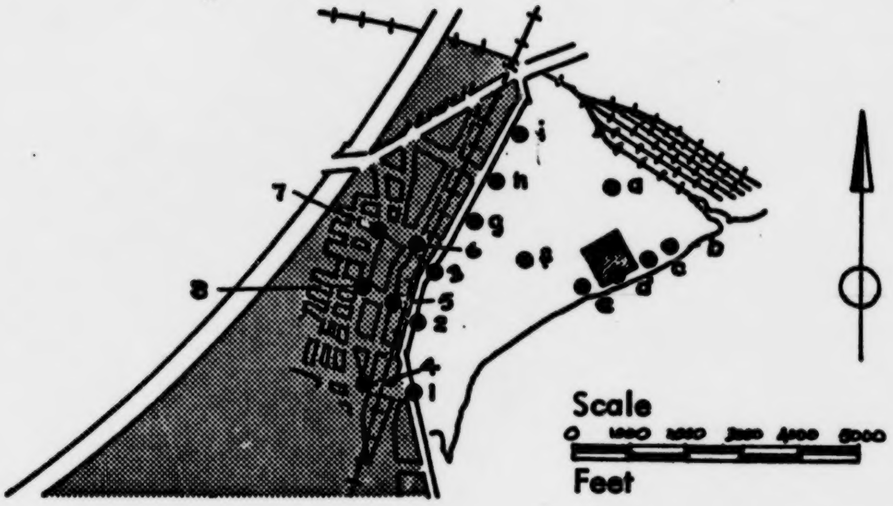
Plant Property Line Noise Levels in dB(A)

	a	b	c	d	e	f	g	h	i
Weekend	55	71	60	60	60	55	54	52	56
Weekday	63	68	60	62	64	63	51	52	53
Weeknight	58	67	59	59	62	61	49	50	54

Key

■	Industrial Noise Source
▨	Residential Area
┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 1-2. Oil Refinery Community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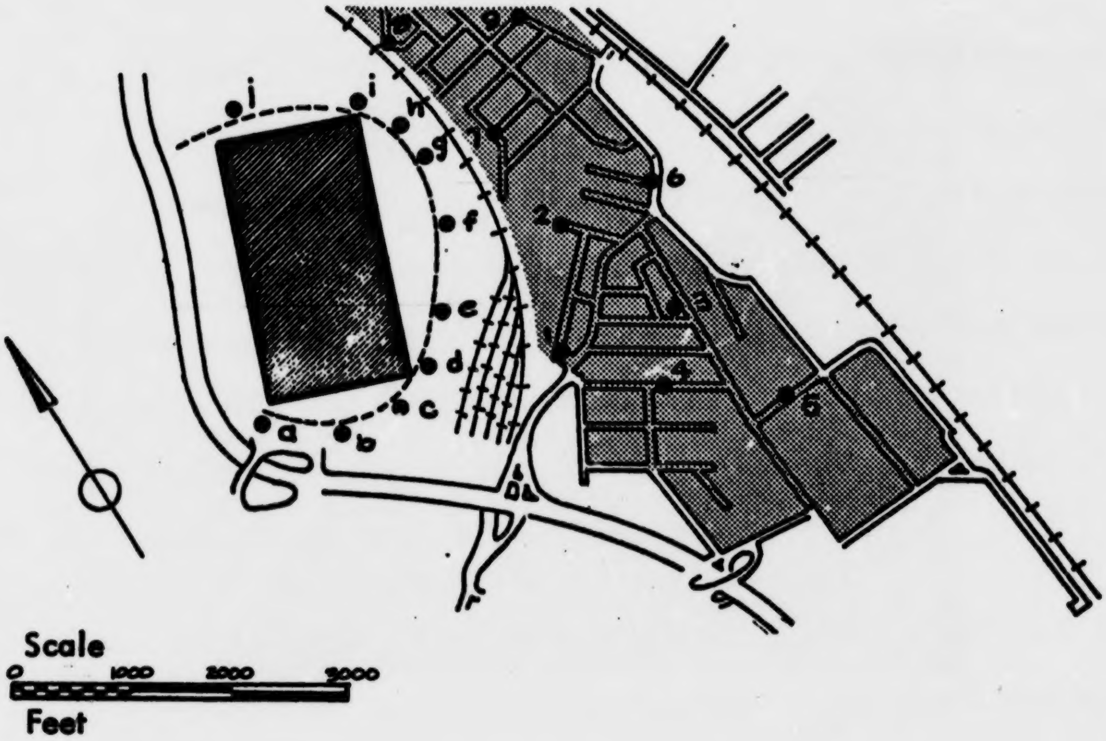
	Community Noise Levels in dB(A)							
	1	2	3	4	5	6	7	8
Weekend	48	50	50	50	52	58	57	54
Weekday	48	51	49	53	55	56	55	54
Weeknight	51	52	52	52	53	56	57	54

	Plant Property Line Noise Levels in dB(A)								
	a	b	c	d	e	f	g	h	i
Weekend	81	58	63	69	64	53	54	59	68
Weekday	64	59	61	72	80	61	59	57	63
Weeknight	68	63	67	70	80	61	60	61	65

Key	
■	Industrial Noise Source
▨	Residential Area
┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 1-3. Power Plant Community



Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8	9
Weekend	47	43	49	45	43	47	45	48	47
Weekday	50	48	50	49	47	54	50	53	50
Weeknight	51	50	50	50	47	52	48	54	48

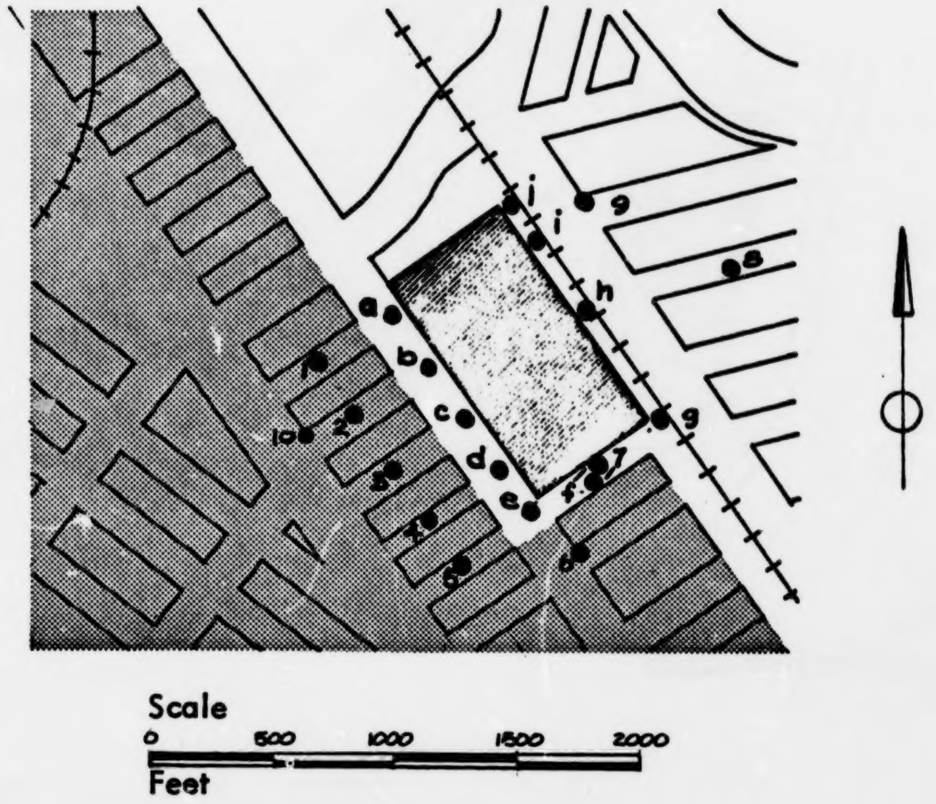
Plant Property Line Noise Levels in dB(A)

	a	b	c	d	e	f	g	h	i	j
Weekend	54	47	46	46	47	54	54	49	54	46
Weekday	58	57	55	53	54	62	57	54	55	54
Weeknight	57	57	56	51	53	58	55	53	54	54

Key

■	Industrial Noise Source
- - - - - - - - - -	Plant Property Line
▨	Residential Area
┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 1-4. Automobile Assembly Plant Community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6
Scale
0
500
1000
1500
2000
Feet

	Community Noise Levels in dB(A)									
	1	2	3	4	5	6	7	8	9	10
Weekend	55	49	53	51	50	50	57	56	51	58
Weekday	53	49	55	49	51	54	59	56	56	55
Weeknight	48	49	53	51	47	49	58	50	55	47

	Plant Property Line Noise Levels in dB(A)									
	a	b	c	d	e	f	g	h	i	j
Weekend	58	59	59	61	58	58	52	50	49	53
Weekday	60	65	64	65	60	60	56	52	57	63
Weeknight	53	63	63	61	58	62	53	43	53	66

Key

▬	Industrial Noise Source
▨	Residential Area
┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 1-5. Can Manufacturing Plant Community

A study of the community noise data indicates that only two (automobile assembly plant and glass manufacturing plant) of the five plants surveyed are the principal source of community noise. Surface transportation noise due to superhighways near the oil refinery and power plant, and bus and truck traffic near the can manufacturing plant either predominate or contribute equally with the industrial plant to community noise.

Discussions with township officials, board of Health officials, and plant management indicate that major complaints are being received at the glass manufacturing plant and sporadic complaints are received from the power plant community only when a gas turbine generator is used. Although the automobile assembly plant is the source of noise in its adjacent community, no complaints have been generated.

It appears that complaints, or a lack of complaints, may not be a satisfactory indicator of the impact of plant noise on its neighbors. Industrial plant neighbors in a community many not object to plant noise even at fairly high levels

(a) if it is continuous,

(b) if it does not interfere with speech communication,

(c) if it does not include pure tones or impacts,

(d) if it does not vary rapidly,

(e) if it does not interfere with getting to sleep, and

(f) if it does not contain fear-producing elements.

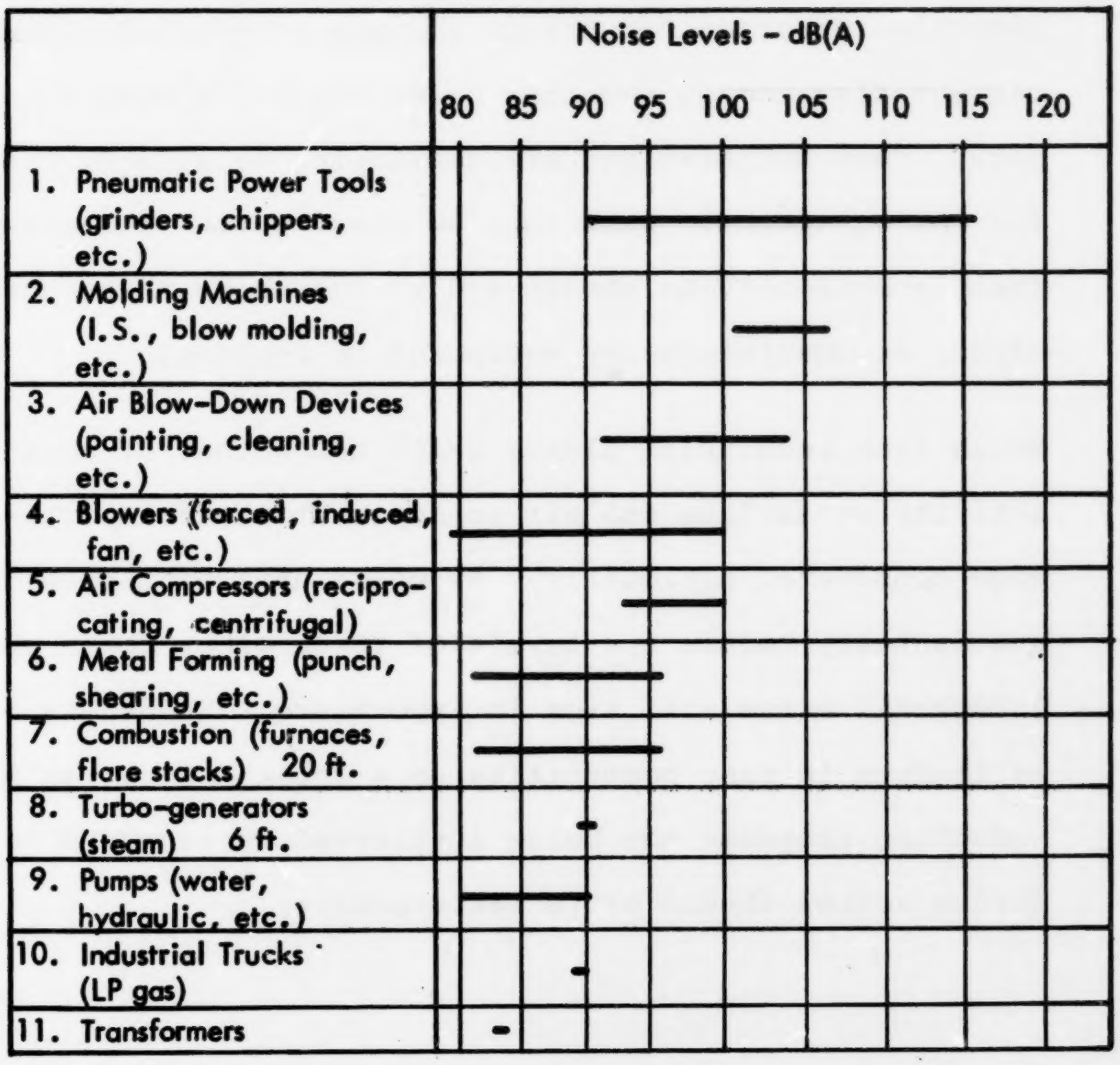
Sometimes political, social, or economic situations develop where noise which is normally objectionable causes no complaints. Often single individuals or families may be annoyed by an industrial noise which does not annoy other plant neighbors. This, in many cases, may be traced to unusual exposure conditions or to interpersonal situations involving plant management personnel.

It is anticipated that the noise levels due to industrial plants will not increase in level or importance relative to the noise from construction activity, surface transportation or aircraft. As noise abatement efforts within the plant motivated by the Occuational Safety and Health Act of 1970 and local "nuisance" laws and zoning ordinances are successful, noise levels may in fact be reduced. Often plant management, in its desire to maintain good community relations, will initiate noise control programs. The goals of such programs are to reduce interior noise to below levels hazardous to hearing (see Table 1-1) and to reduce exterior noise to below levels which generate complaints although complaints may not be a satisfactory indicator of noise impact.

Industrial plant noise, anticipated at the early phase of plant development, can be readily controlled. Noise reduction programs for plants already in operation are usually directed at reducing noise along its transmission path. Many corporations are developing noise specifications for new equipment. When used by their purchasing agents, these specifications should aid in the noise abatement effort as obsolete noisy equipment is replaced.

Noise from industrial plants falls below that of construction activity or surface and air transportation in importance when considered nationally. As noise abatement efforts successfully reduce the levels of these other noise sources, industrial noise will rise in importance. When this occurs, as it does in many communities on a local basis, the noise reduction programs now being instituted or reserved for future action should prove satisfactory.

Table I-I - Range of Industrial Machinery, Equipment and Process Noise Levels Measured at Operator Positions (except where noted)



2. INTRODUCTION

2.1 Background

Of all the pollutants, noise is the only one that does not leave a residue. To determine how much noise has been made at any location, it must be measured as it is being made, or at least recorded precisely for measurement and analysis at a later time. In contrast, gaseous emissions and particulates may be collected and examined at a later time, and water pollution can be measured in terms of either the emission or the resultant water quality. Since noise must be measured either as a source emission or as a remotely detected signal that ceases when the emission ceases, it has been difficult to examine the environmental distribution of transient noise signals mixed with continuous noise and to study the environmental effects. It is also difficult to study the adverse effects of noise because there are no directly observable tangible effects of noise on people when the levels of noise are below those that will cause temporary loss of hearing; and these levels are well above those that cause interference with speech communication and distraction from creative tasks. It is, however, the continued small interference with the daily life of individuals that appears to cause annoyance or to convey unpleasant information. These annoyance and information effects combined with distraction appear to be capable of generating strong and generalized psychophysical stress, negative emotional responses, of preventing self-renewal, of causing some direct psychophysical responses. These include changes in skin temperature, blood pressure, pulse rate, and other indicators of autonomic changes in adrenocortical systems. In other words, the whole psychophysiological system of the body may respond to noise without any knowledge of this response on the part of the individual exhibiting the response. The result may be solely physical or through the complex psychophysiological response chain may generate strong, or even violent, behavioral reactions on the part of the auditor. The system is so complex within the context of the entire socio-political area that today entire municipalities are deeply committed to noise abatement programs. The levels of noise are quite disparate and confirm the premise that it is not necessarily the level, but the information content of the noise that is significant.

It may be assumed that more is known about the noise environment of man than about man's response to noise. This is not the case. Although considerable work has been done in an effort to delineate the exposure of various groups or political subdivisions to noise, to date no system has been developed which simply and suitably describes a noise environment. Even a complex description of environmental noise may be inadequate for predicting human response.

Noise is a multidimensional phenomenon and its basic physical attributes do not adequately describe it in terms that permit simulation for laboratory studies, or for rank ordering or comparison if the noises are from sources that are not almost identical. Among the problems of describing any given noise environment are the lack of descriptors, much less scales, for sound "quality." Current technology makes use of only the simplest descriptors, the physical parameters: frequency, level, and time (duration) usually. However, it is well known that human response at levels below those causing speech interference is sensitive to the number and phase relationship of pure tones, whether alone or buried in random-type noises. The on-off behavior of some noises such as the cycling of air-conditioning dequipment has a strong influence on human acceptability of noise, but most work to date looks only at the total "on" time.

Furthermore, the information content of the noise may vary widely. The un-air-conditioned neighbor may be reminded of the social status associated with the fully air-conditioned home whenever he hears his neighbor's machine cycling at a typical eight- to twelve-minute rate. Industrial noise may be a reminder to some individuals of the social and economic status that they believe they might enjoy if the industry were not there. Aircraft noise, sirens, and explosive sounds often carry fear stimuli for urban and suburban dwellers.

It is within this context that the following goals of this program were formulated:

(1) Measure and appropriately describe sources of noise in industry that contribute to environmental noise.

(2) Measure the resultant noise in the community in general.

(3) Examine the various effects of the environmental noises measured or located on the people exposed, and identify or relate in some way the various human response phenomena associated with audition of the noise sources in the community. This would include as many of the various psychophysiological effects as can be related within the present state-of-the-art, as well as an estimate of other

effects that are only now being limned by current exploratory research.

(4) Examine the current situation with respect to noise abatement and develop a picture of the current level of activity and the reasons for the activity in various industries (other than current federal statutes related to hearing conservation), and identify the activity that initiated noise abatement action.

(5) Develop a picture of the present state-of-the-art in noise abatement in industry, including the environmental control efforts, using non-source-related techniques such as barriers, enclosures, and site planning, as well as the technology of source-related equipment and techniques. This work will include discussions of available technology not now applied, possible innovative approaches that might be explored, and the payoffs and tradeoffs that are available with more effective noise abatement, both generally and specifically.

(6) Explore the planning currently going on for further means of achieving noise reduction both by abatement

procedures and hardware and by means of process redesign and new production technology, and outline those areas and items for which noise control is currently either not considered feasible, or for which none has been contemplated, along with the rationale of the manufacturers and users that leads to this situation.

The goals described above were accomplished using state-of-the-art data acquistion techniques and appropriate instrumentation, measurement methodology, and analysis methods. The measured sound levels are related to the behavioral responses developed either from theoretical considerations, field survey, or empirical relationships developed by earlier studies. Further, an assessment of the state-of-the-art with respect to noise abatement methods and procedures was developed from discussions with management, engineering, and industrial hygiene personnel of industrial plants and equipment manufacturers, and a thorough search of the current literature.

2.2 Site Selection

This study was initiated with a search for typical industrial plants with acceptable communities from the following five categories:

(a) Rolling Mill

(b) Assembly Line Plant

(c) Oil Refinery

(d) Textile Mill

(e) Processing and Stamping Plant

Difficulties encountered in locating typical plants reflecting the above categorization due to time, economic, and geographic constraints, required that the industrial activity used for this study be recast into the following categories:

(1) Product Fabrication
    (a) Metal fabrication
    (b) Molding
(2) Assembly Operations
(3) Power Generation
(4) Petrochemical Process

Five industrial plants located in the northeastern United States were selected. Table 2.2-1 lists these plants by types, categories, and number of similar units in the United States.

Table 2.2-1 - Types of Industrial Plant Selected

Typical Industrial Plant	Category	Number in United States
Can Manufacturing Plant	Metal Fabrication	300
Glass Manufacturing Plant	Molding	305
Automobile Assembly Plant	Assembly Operation	98
Electric Power Plant	Power Generation	3429
Oil Refinery	Oil Refinery	438

2.3 Noise Surveys

2.3.1 Plant Noise Sources

The basic approach to the plant noise investigation was based on a detailed inspection of the plant, the objective being to locate the major noise sources with respect to both plant and neighboring environments. Measurements were made as detailed below in order to define the source noise levels:

(1) A-weighted noise levels and overall noise levels were observed using a precision sound level meter for the purpose of providing data against which to check tape recorded signals.

(2) Tape recordings of the noise levels at points located at appropriate far-field or quasi-free field distances from the source machine or device under investigation were made using precision instrumentation-type tape recorders. Acoustic-calibrator signals were recorded at appropriate time intervals to determine the absolute signal levels. Complete system calibrations were performed on a periodic schedule throughout the measurement program in order to provide level corrections for

the one-third octave bands as required. Measurements were made for appropriate time periods to insure that the data acquired will represent the full cycle time of various components of the machine or device under test.

2.3.2 Community Noise Sources

Noise levels (A-weighted) at the plants' boundaries were observed during a weekend or holiday period when the plants were either secured or in a mode of operation different from the normal work-week operation. During this weekend or holiday period, the community residual noise levels (A-weighted) were also observed at residential locations in the adjacent communities. Magnetic tape recordings were obtained at the same residential locations discussed above during two work days. Data were recorded during daytime, evening, and nighttime periods. The locations at the plant property line and in the communities are presented in Figures 1-1 through 1-5.

2.3.3 Data Acquisition

Noise measurements were accomplished within the industrial plants and in the community adjacent to these plants using precision sound level meters and magnetic tape recording equipment which meets or exceeds all pertinent United States regulations or standards.

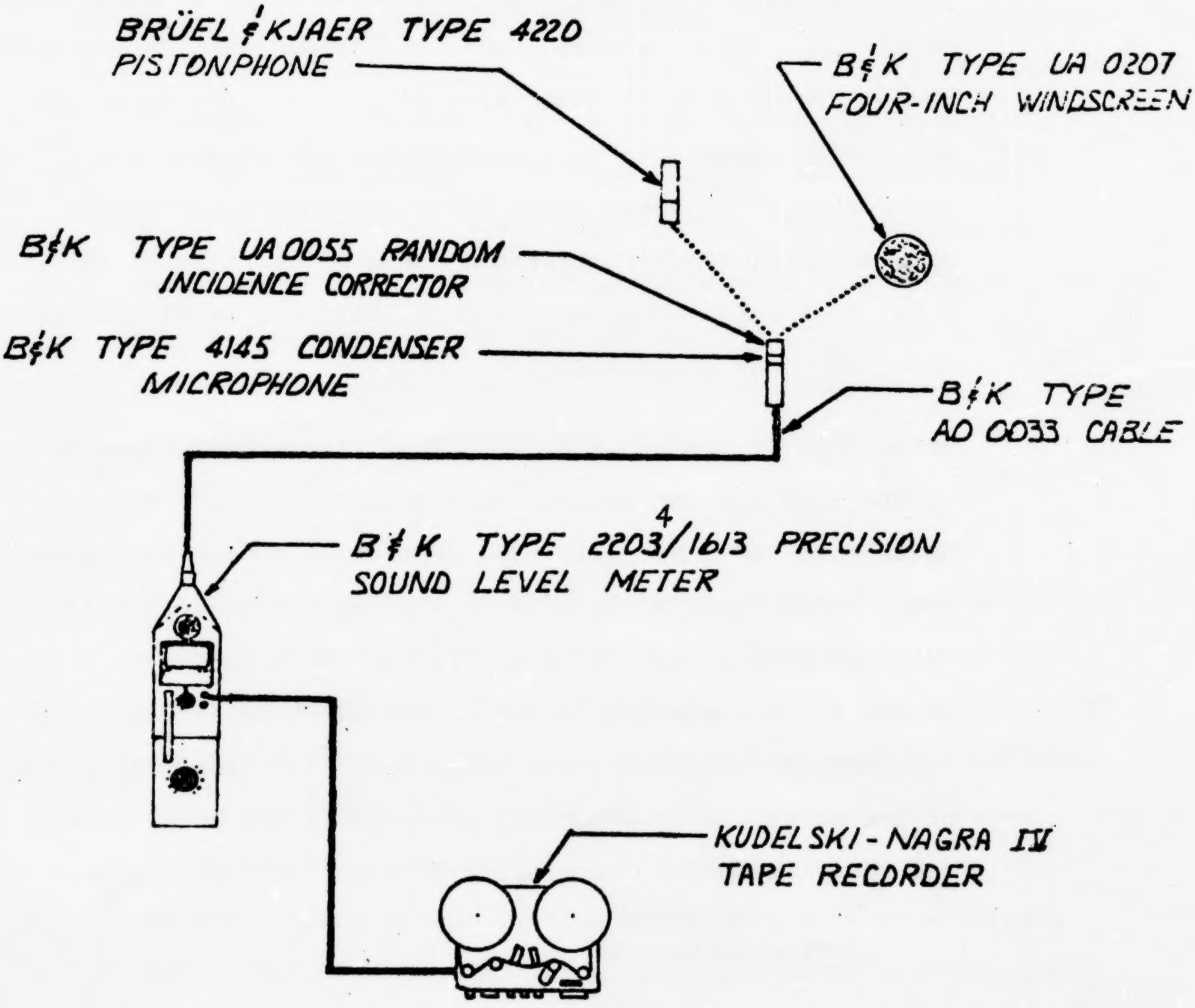

BRÜEL & KJAER TYPE 4220
PISTONPHONE
B & K TYPE UA 0207
FOUR-INCH WINDSCREEN
B & K TYPE UA 0055 RANDOM
INCIDENCE CORRECTOR
B & K TYPE 4145 CONDENSER
MICROPHONE
B & K TYPE
AD 0033 CABLE
B & K TYPE 2203/1613 PRECISION
SOUND LEVEL METER
4
KUDELSKI-NAGRA IV
TAPE RECORDER

Figure 2.3.3-1. Block Diagram of Recording Instrumentation System

Noise levels (A-weighted) at locations within the plants, at the plants' property line, and in the community were obtained using Bruel and Kjaer Precision Sound Level Meters, Model 2203, 2204, or 2206, using the "slow" damping characteristic. Model 4145 or Model 4148 Bruel and Kjaer capacitor microphone cartridges were used as the electroacoustic transducer. The above noise level monitoring system was pre- and post-survey calibrated using either a Bruel and Kjaer pistonphone calibrator, Model 4220, or level calibrator, Model 4230, as applicable.

Recordings of the noise at locations within the plants or in the adjacent communities were obtained using a Kudelski Nagra Model IV-B magnetic tape recorder with the Precision Sound Level Meter Model 2203 or 2204 as its preamplifier, and microphone, Model 4145 or 4148 as the transducer. Figure 2.3.3-1 presents a block diagram of the above instrumentation system. An instrumentation list, Table D-1, of the noise survey equipment used, including make, model, and serial number of each unit, is found in Appendix D.

2.3.4 Data Reduction

The information previously recorded on magnetic tape using the Nagra Model IV-B magnetic tape recorder was retrieved by playing the tape back on a Crown 800 Magnetic Tape Recorder. To insure that the record-playback frequency response was linear, the signal from the Crown was processed by a General Radio Type 1925 multifilter. This unit includes a calibrated attenuator in each of 30 one-third octave filter channels (25 Hz to 20,000 Hz) which is used to correct transducer and tape recorder frequency reponse non-linearities. Table D-2 in Appendix D lists the attenuator corrections required due to windscreen, microphone, random incidence corrector, sound level meter, and Nagra/Crown tape recorder non-linearities.

2.3.5 Data Analysis

The recorded data were analyzed in a number of ways using the General Radio Type 1921 Real-Time Analyzer controlled by a digital computer. The major components of the analyzer are the multifilter discussed above and a Type 1826 multichannel root-mean-square (rms) detector. The detector processed the signal from the multifilter digitally by sampling the filter outputs and converting these data to digital binary form. The binary information is used by a digital processor to compute rms levels. These outputs, one-third octave band pressure levels from 25 Hz to 20,000 Hz plus linear, A-weighted, B-weighted, and C-weighted noise levels are stored in a

Digital Equipment Corporation PDP-8/I digital computer for further computation or later printout or punchout on paper tape.

One-Third Octave Band Frequency Response

The analog signals from the multifilter may be sampled for periods from 1/8 second to 32 seconds by the rms detector before computation of rms levels. The data from in-plant noise sources were sampled for 32 seconds, except when analyzing noise data with impulsive characteristics such as chipping hammer bursts and grinding operations at the automobile assembly plant. Impulsive data were sampled for a duration sufficient to include most of the operation. The one-third octave band sound pressure levels were printed out, plotted, and are the figures seen in Section 3. of this report.

Statistical Data Analysis

The analog signals from the multifilter may be sampled repetitively. That is, the rms detector computes one-third octave band sound pressure levels from samples obtained during an integration period. These data are stored while the detector computes again from samples obtained during the next integration period. The sequence of sound pressure level data thus obtained forms a sampled data set which is used for statistical computations.

The following procedure was used:

(1) The Real-Time Analyzer was instructed by the PDP-8/I digital computer to compute 100 groups of one-third octave band sound pressure level data points. Each computation was accomplished using a one-second integration period.

(2) The one-third octave band sound pressure levels were used by the digital computer to compute octave band sound pressure levels.

(3) Information from 100 sets of octave band sound pressure level data was punched on paper tape.

(4) The data stored on paper tape was used as input to a Statistical Data Analysis program written in FORTRAN IV programming language.

(5) The Statistical Data Analysis program was used by an AL/COM time-sharing system to compute and print out fundamental statistical values and percentile values.

The fundamental statistical values consist of maximum sound pressure level, minimum sound pressure level, number of occurrences, arithmetic mean, median, and standard deviation for each octave band. The 10th, 50th, and 90th percentile levels are computed for each octave band, linear, A-weighted, B-weighted, C-weighted, and D-weighted. In addition, the Speech Interference Level (SIL) is computed. A flow chart of the procedure described above is presented as Figure D-1. An example of the output format is reproduced as Figure D-2. Both figures are found in Appendix D.

Noise Level (A-weighted) Histograms

The Real-Time Analyzer was instructed by the PDP-8/I to compute 50 groups of one-third octave band sound pressure level data points. Each computation was accomplished using a four-second integration period. The one-third octave band sound pressure data were weighted and energy summed to produce an A-weighted noise level point. The sequence of these data points was printed out in a histogram format, an example of which is presented in Figure D-3 of Appendix D.

2.4 Examination of Noise Effects

The in-plant, plant fence line, and neighboring community noise data in the form of A-weighted noise levels, one-third octave band sound pressure levels, and statistical octave band sound pressure levels were reviewed for an understanding of the community noise climate, and to determine whether the industrial plants are the major noise sources in each community. To aid in understanding the impact of industrial plant noise, Community Noise Equivalent Levels* were computed for each community measurement location from the intrusive A-weighted noise levels observed there.

The actual effects of the industrial noise on community residents were determined from interviews with city police, boards of health, plant management, and township officials. Land use information was gathered from the appropriate state and local planning departments and zoning maps.

Realizing that the sample size was small (1.5 percent of all industrial plants were represented), A-weighted noise levels and community impact information from 22 additional noise-producing facilities (18 industrial plants) were studied. Community Noise Equivalent Levels were also computed from these data.

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*Development of CNEL is discussed in the Wyle Laboratories Contractors' report to Environmental Protection Agency.

2.5 Noise Abatement Technology Assessment

An assessment of the current state-of-the-art in industrial noise abatement was constructed. This included appropriate bibliography, as well as the specific information needed to evaluate the capability of the present and future efforts to achieve the level of noise abatement that is required to meet the various Federal, state, and local noise regulations, as well as the predicted future requirements. Such an assessment included:

(1) Presentation by category of machine and environment of the expected source and environmental noise reductions that may be achieved through noise abatement techniques currently in use, planned, and possible through state-of-the-art methods.

(2) Outline of the methodology through which noise reduction can be planned and achieved as a general methodological technique.

(3) An evaluation of the various program payoffs and tradeoffs that may be achieved through noise abatement.

(4) A summary of plans for future noise reduction including as much information as can reasonably

be acquired from cooperating industries. Planned cost allocations are presented where available, along with estimates of expenditures over the past five years.

(5) Estimates on the potential for noise control of industrial machines including large machine tools, air compressors, pumps, industrial trucks, molding machines, punch presses, petrochemical heaters, and waste gas torches.

Referenced in Appendix A, are the technical literature which formed the basis for the technology assessment. Additional books, monographs, and papers of interest in this field are presented in Appendix B as a Selected Bibliography. Current noise standards and specifications are listed in Appendix C.

3. FIELD SURVEY RESULTS

The first step in any program to determine the environmental impact of noise from industrial plants on the surrounding community should be one of characterizing the plant noise sources. One must first identify the noise sources, determine the source noise levels, and describe their frequency domain characteristics.

From the point of view of noise abatement and control, industrial noise sources can be classified in a very general way into the following major types:

(1) Impact noise sources, e.g., punch presses, stamping machines, and hammers.

(2) Mechanical noise sources, e.g., machinery unbalance, resonant structures, gears and bearings.

(3) Fluid flow noise sources, e.g., fans, blowers, compressors, turbines, and control valves.

(4) Combustion noise sources, e. g., furnaces and flare stacks.

(5) Electromagnetic noise sources, e.g., motors, generators, and transformers.

The purpose of the in-plant inspection and survey was to identify the major noise sources and to obtain acoustical measurements to determine the character and the noise levels of these noise sources in order to evaluate their environmental impact on the communities surrounding the industrial plants.

3.1 Glass Manufacturing Plant

Glass bottles are manufactured at this plant by Individual Section (I.S.) molding machines. The glass, in molten form, is "blow molded" by the I.S. machine to the required size and shape. The glassware is cooled and transported by conveyer to an annealing oven. The finished glassware is then recooled and transported to quality control inspection stations.

3.1.1 Plant Noise Sources

It became apparent during the plant inspection and survey that the major source of high frequency noise noticeable throughout the plant is the discharge of high pressure air. High pressure air is widely used for pneumatic control and operation of glass molding machines. This air is generally vented directly into the atmosphere from cylinder and valve block ports of glass molding machinery. Turbulent mixing of the exhaust air with the ambient air is the basic noise-producing mechanism.

An analysis of the data obtained in the glass manufacturing plant showed that the three major noise sources are:

(1) Mold cooling fans,

(2) The blow-molding dies, and

(3) The I.S. machines.

3.1.2 Source Noise Levels

Figures 3.1.2-1 through 3.1.2-3 present the one-third octave band sound pressure levels for these three sources respectively. Figure 3.1.2-1 shows the one-third octave band sound pressure levels measured near the inlet of a typical mold cooling fan. The fan supplies cooling air to the I.S. machine molds. These noise levels were measured in a highly reverberant area of the plant and are typical of the levels expected from 100 to 200 horsepower high pressure fans of this type. The noise level is 100 dB(A). Fans are the primary source of noise in air moving systems, and the radiated noise consists of discrete tones superimposed on a broad-band noise spectrum.

Figure 3.1.2-2 shows the one-third octave band sound pressure levels one meter from an I.S. machine blow-molding die. The noise level is 105 dB(A).

Figure 3.1.2-3 shows the one-third octave band sound pressure levels measured in the general area of an I.S. machine.

This spectrum consists of the sum of the component sources of the machine. The noise level is 101 dB(A). Collectively, the I.S. machines are the major noise source within the glass manufacturing plant contributing to the external plant noise which affects the surrounding community.

Compressor noise, while not a major sources, does contribute to the plant noise climate. Figure 3.1.2-4 shows the one-third octave band sound pressure levels measured in the plant compressor room.

These noise sources are located within a corrugated cement-asbestos paneled building containing acoustical louvers at the air inlets and the air exhausts.

3.1.3 Community Noise Levels

The glass manufacturing plant is located in a small suburban community with a population of 5,535 persons and a population density of 2,838 persons per square mile. The residents' average annual income is $14,240.00. The nearest residential community to the plant is on a hill adjacent to and overlooking the plant. Figure 3.1.3-1 is a map of the area which shows the property line and community measurement locations. All the measurement locations except Location 13 in the community are situated in a residential area where housing units are of the multifamily type. Location 13 is situated to the southeast of the plant where housing units are of the single-family detached type. Figures 3.1.3-2 through 3.1.3-14, present typical community statistical noise spectra obtained from both the daytime and nighttime community noise surveys.

The I.S. machines in evidence throughout the plant use a great deal of air which is presently exhausted without the use of mufflers. The broad-band characteristics of this noise source are in evidence at Locations 1 and 2 and are the cause of community annoyance. It is known that complainants reside near Location 1. The nighttime noise at Location 11 contains discrete frequency components in the 125 Hz octave band, presumably due to local effects such as a neighbor's air-conditioner or an exhaust fan.

Histograms of noise levels (A-weighted) for daytime and nighttime for all the community measurement Locations 1 through 13 are presented in Figures 3.1.3-15 through 3.1.3-27 respectively. The L_{10} A-weighted intrusive noise levels for daytime, evening and nighttime for each measurement at each community location are shown in Table 3.1.3-1. These L_{10} A-weighted noise levels at each location were energy averaged and the resulting data were used for computation of Community Noise Equivalent Level (CNEL) discussed in Section 4.2.4 of this report.

The average residual (L_{90}) noise levels (A-weighted) at each measurement location for weekday, weeknight, and weekend periods are given in Figure 3.1.3-1. It is interesting to note that the ambient noise levels for Location 2 in the community are greater than those in other locations. The reason for this is that Location 2 is very close to the inlet ventilation ducts at the plant. Note the corresponding high property line ambient noise levels at Location j.

The statistics of the community noise are represented by the 90th, 50th, and 10th percentile levels. The 90th percentile level, (L_{90}), represents a level above which the noise exists for 90 percent of the time; the 50th percentile level, (L_{50}), represents a level above which the noise exists for 50 percent of the time; the 10th percentile level, (L_{10}), represents a level above which the noise exists for 10 percent of the time. The 90th, 50th, and 10th percentile values are considered as representing the ambient, median and intrusive noise levels, respectively. The L_{90}, L_{50}, and L_{10} percentile values were obtained from 100 data samples.

3.2 Oil Refinery

An oil refinery is a complex system of furnaces, piping systems, heat exchangers, high pressure vessels, and receiving tanks.

The noise sources within an oil refinery are furnaces, compressors, heat exchanger cooling fans, flare stacks, pumps, control valves, and air and steam piping leaks. The flare stacks are used to burn excess gases.

3.2.1 Refinery Noise Sources

An analysis of the noise sources identified and measured in the oil refinery showed that there are two major types of noise sources. These are:

(1) The petrochemical furnaces and their associated air cooled heat exchangers, and

(2) The centrifugal compressor systems.

Furnace noise represents a combination of several noise-producing mechanisms: first, the noise produced by the gasified fuel; second, the noise produced by the intake of primary and secondary air; third, the noise produced by the combustion process itself. The fuel flow generates high frequency noise and the air intake system produces a low frequency noise. Combustion noise is not as significant as that produced by the air and gas flow.

3.2.2 Source Noise Levels

Figure 3.2.2-1, shows the one-third octave band sound pressure levels measured near a petrochemical furnace and its associated fan-driven, air cooled heat exchangers. The noise level is 97 dB(A).

There are two basic types of compressors generally used in oil refineries. The first is the rotary type, such as the centrifugal and axial compressor where compression takes place by blades pushing the air much in the same manner as in a fan. The second type of compressor is the positive displacement type which may be either a piston compressor or a lobe-type compressor. The sources of noise in both types are periodic inlet and exhaust pulses resulting in mechanical noise radiated from the casing of the machine and structure-borne and fluidborne noise radiated from the discharge piping system.

Figure 3.2.2-2 shows the one-third octave band sound pressure levels measured in the oil refinery hydrogen compressor station between a 2000 horsepower centrifugal compressor and a 7000 horsepower centrifugal compressor. The noise level is 98 dB(A).

The low horsepower of pumps makes them individually minor noise sources, but collectively they serve to raise the general noise level in an oil refinery. The one-third octave band sound pressure levels of other noise sources such as fin fans, flares, furnaces, storage tank area, and catalytic cracking unit are shown in Figures 3.2.2-4 through 3.2.2-8.

3.2.3 Community Noise Levels

The oil refinery is situated within a municipality with a population of 41,409 persons and a population density of 3.781 persons per square mile. The average annual income per household is $13,824.00.

The oil refinery is located in a heavily industrialized area and is bounded on the east, north, and west by highways. The turnpike going north-south is a heavily travelled major route. Two separate communities are close to the refinery. To the south the refinery is separated from the community by its oil storage tank farm and to the north it is separated from the community by a highway which provides access to the turnpike.

Figure 3.3.3-1, shows the measurement locations in the community and on the plant property line. The residential areas in the north, where Locations 1, 2, 3, and 4 are situated, are mainly one- and two-family housing units. The measurement Locations 5, 6, and 7 are situated in an apartment and tenement district separated from the plant by a buffer zone consisting of a cemetery. The measurement Locations 8 and 9 to the south of the plant are situated in a residential area consisting mainly of one-family housing units, mixed with some scattered business activities.

Figures 3.2.3-2 through 3.2.3-9 represent octave band noise levels presented statistically for community Locations 2 through 9 respectively. Data for Location 1 was affected by the presence of a neighboring chemical plant and is, therefore, not shown. In general, except for Location 5 the daytime (background) ambient noise level represented by the L_{90} curve exceeds the nighttime (background) ambient noise level. These figures present data consisting of general broad-band characteristics, which are representative of industrial areas with considerable surface transportation.

It is only isolated instances (L_{10}) where traffic may produce tonal characteristics, see Figure 3.2.3-4. The major oil refinery noise sources, see Figures 3.2.2-1 through 3.2.2-8, are not recognizable as such in the community.

The noise levels (A-weighted) are presented as histograms for Locations 1 through 9, as Figures 3.2.3-10 through 3.2.3-18 respectively.

The L_{10} A-weighted intrusive noise levels for each measurement at each community location for the daytime, evening, and nighttime are shown in Table 3.3.3-1. The residual noise levels at each measurement location in the community and at the plant property line are given in Figure 3.2.3-1.

3.3 Power Plant

A power plant is a complex system of furnaces, gas turbine and steam turbo-generators, transformers, and associated equipment. The power plant surveyed contains five steam turbo-generators and one gas turbine generator. The noise sources within the power plant are forced draft blowers, control valves, induced draft fans, compressors, transformers, and the turbine generators themselves.

3.3.1 Plant Noise Sources

Turbines, both gas and steam, are major sources of noise in power plants. The major noise sources in a typical gas turbine driven compressor installation are the compressor piping, compressor vibration, exhaust duct radiation, shell radiation, the turbine exhaust and the gas turbine inlet. The gas turbine inlet is the loudest and most annoying noise-producing mechanism, because of its characteristic high frequency whine corresponding to the blade passage frequency of the first stage of the compressor. The gas turbine exhaust is lower in frequency and sounds more like the noise produced by a jet aircraft during take-off.

A considerable amount of noise is radiated from the generator casing. The turbine exhaust shroud also radiates a large amount of exhaust noise. In addition, there is some noise radiated by the turbine housing, and when the entire unit is mounted on a structural steel framework there may be a considerable amount of structureborne noise transmitted from the machinery to the framework.

Fluidborne and structureborne noise transmitted to piping systems and other associated equipment may be major sources of power plant noise. This noise is radiated by the piping, floors, walls, and ceilings unless corrective measures to block its transmission path are accomplished.

3.3.2 Source Noise Levels

An analysis of the data obtained in the power plant showed that the three major noise sources are:

(1) Draft fans (both induced and forced-type),

(2) Turbine generators, and

(3) Air compressors.

Figures 3.3.2-1 and 3.3.2-2 present the one-third octave band sound pressure levels measured between two induced draft fans and near a forced draft fan outside the main power plant building, respectively. In forced draft fan systems, the fan inlet is the major source of noise. The fan noise spectra are combinations of broad-band and discrete noise. The discrete noise shows up as pure tones at multiples of the fan rotational frequency. These spectra are typical for these fan types and are a function of the mechanical construction and the aerodynamic forces of the fan. The noise levels are 68 dB(A) for the induced draft fan and 96 dB(A) for the forced draft fan.

Figure 3.3.2-3 shows the one-third octave band sound pressure levels measured near a 100 megawatt steam turbine generator. The noise level is 93 dB(A).

Figure 3.3.2-4 shows the one-third octave band sound pressure levels measured in the compressor room area. The noise level is 97 dB(A).

3.3.3 Community Noise Levels

The power plant is located in a rural community which borders it to the west and south. To the east is a river, and to the north is an oil refinery (not the refinery discussed in Section 3.2). The power plant lies in a municipality whose population is 98,944 persons with a population density of 4,283 persons per square mile. The average annual income per household is $10,951.00.

The measurement locations in the community and on the plant property line are shown in Figure 3.3.3-1. The power plant is located in a heavily industrialized area of the community. The measurement Locations 1 through 8 in the community are in a residential area consisting of single-family detached housing units mixed with some scattered neighborhood business centers. Community noise levels for Locations 1 through 8 are presented as statistical noise spectra in Figures 3.5.3-2 through 3.5.3-9 respectively.

The noise spectra for two Locations, 1 and 6, indicate that broad-band noise predominates, while the noise spectra for Locations 3 and 5 indicate that the background contains discrete frequency noise during the day at Location 3, and during the night at Location 5. The low frequency noise evident inside the power plant is not evident in the community data. The noise in the 125 Hz band at Location 5 and in the 250 Hz band at Location 3 may be due to local effects such as air-conditioners, basement workshop equipment, etc.

Figures 3.3.3-10 through 3.3.3-17 show the daytime and nighttime histograms of A-weighted noise levels for community Locations 1 through 8 respectively. The L_{10} A-weighted intrusive noise levels for each measurement location for the daytime, evening, and nighttime are shown in Table 3.3.3-1. The residual noise levels at each measurement location in the community and on the property line are given in Figure 3.3.3-1.

3.4 Automobile Assembly Plant

The automobile assembly plant assembles standard-size cars and small trucks. Employees use, as labor assist devices, pneumatic and electric powered hoists and tools such as grinders, impact wrenches, angle wrenches, and hole saws. Also, body painting and body cleaning operations use air blowdown devices. The noise created by pneumatic tools is airborne, and the major noise source is the tool air exhaust.

3.4.1 Plant Noise Sources

An analysis of the noise sources identified and measured in the automobile assembly plant indicates that three operations using pneumatic tools may be classified as major noise sources. These three operations are:

(1) The rough grinding operations,

(2) The weld destruct operation by chipping, and

(3) The piercing and hole cutting operation.

In addition, forced air blowers and air compressors are major in-plant noise sources.

There are three broad classifications of pneumatic tools: rotary, piston, and percussion type. In a typical pneumatic tool, the air passes through the handle, past a control valve, through end plates, and into a chamber in the cylinder where it presses against blades that are free to slide in the slots of a rotor. As the air expands against the blades, the rotor turns until exhaust ports are passed in the cylinder, allowing the air to discharge into the atmosphere. Percussion tools such as the chipper are the noisiest of all pneumatic tools. However, the very act of grinding and chipping on a large metal object will create more noise than the actual tool itself. The combination of tool and operation noise covers a broad-band, but the levels are greatest in the high frequency bands.

3.4.2 Source Noise Levels

Figure 3.4.2-1 presents the one-third octave band sound pressure levels measured near a rough grinding operation. The noise level is 108 dB(A). Figures 3.4.2-2 and 3.4.2.3 present the sound pressure spectra for the weld destruct chipping operation and the piercing and hole cutting operation. The noise levels are 115 dB(A) and 109 dB(A) respectively.

Figure 3.4.2-4 presents the one-third octave band sound pressure levels measured near a forced draft air blower. The noise level is 98 dB(A).

Figure 3.4.2-5 presents the one-third octave band sound pressure levels measured near two reciprocating compressors. The noise level is 94 dB(A). Figure 3.4.2-6 presents the one-third octave band sound pressure levels measured near a typical air blow-off operation. The noise level is 102 dB(A). Figures 3.4.2-7 through 3.4.2-12 present the one-third octave band sound pressure levels of blow-off operations, pneumatic tools and metal finishing operations.

3.4.3 Community Noise Levels

The automobile assembly plant is bounded on the west by a major highway and on the east by a suburban community with a population of 10,539 persons, with a population density of 410 persons per square mile. The average annual household income for this community is $13,441.00.

The community is adjacent to the rear of the plant. At the rear, but still a part of the plant, are railroad switching tracks used to bring preassembled parts into the plant. These parts are stored in an area between the plant's rear and the assembly floor where the major noise sources are located. The plant operates on a two-shift basis, with assembly operations halted for maintenance and clean-up after midnight.

The measurement locations in the community and on the plant property line are shown in Figure 3.4.3-1. The automobile assembly plant is located in an industrial area. All the measurement Locations 1 through 9 are situated in a residential community consisting of single-family detached housing units mixed with some scattered business activities.

Community noise for the Locations 1 through 9 are presented as statistical noise spectra in Figures 3.4.3-2 through 3.4.3-10 respectively. These spectra are not directly relatable to the major noise sources within the plant. Some of this noise is due to the railroad operation at the rear of the plant.

The discrete frequency components in evidence at Locations 3,6, and 7 (see Figures 3-4-3-4, 3.4.3-7, and 3.4.3-8) in the 125 Hz octave band may be due to local effects such as window exhaust fans of air-conditioners, while the discrete frequency in evidence in the 4000 Hz octave band at nighttime Location 8 may be due to insect noise.

The noise levels (A-weighted) are presented as histograms for Locations 1 through 9 for the daytime and nighttime on Figures 3.4.3-11 through 3.4.3-19. The L_{10} A-weighted intrusive noise levels for each measurement location for the daytime, evening, and nighttime sampling periods are shown in Table 3.4.3-1. The ambient noise levels at each measurement location in the community and on the property line are given in Figure 3.4.3-1.

3.5 Can Manufacturing Plant

The process of can manufacturing requires metal forming and metal cutting, e.g., punching, shearing, pressing, and soldering. Metal fabricating operations and their associated equipment are in general noisy. Noise radiating from the noisy operations is transmitted throughout the reverberant plant building. This may mean that an employee performing a relatively quiet operation at one end of the plant may be exposed to noise from a noisy operation at the other end of the plant.

3.5.1 Plant Noise Sources

An analysis of the noise sources identified and measured in the can manufacturing plant indicates that the three major noise sources are:

(1) The air compressor system,
(2) The ring pull punch presses, and
(3) The internal lacquer spray line.

Among the other sources that contribute to the in-plant noise are body maker slitters, different types of punch presses, flangers, air test system, beaders and seamers.

3.5.2 Source Noise Levels

Figure 3.5.2-1 presents the octave band sound pressure levels measured at the air compressor section of the plant. The noise level there is 99 dB(A).

Figure 3.5.2-2 presents the octave band sound pressure levels measured near a ring pull punch press. The noise level is 104 dB(A).

Figure 3.5.2-3 presents the octave band sound pressure levels measured near the internal lacquer spray line. The noise level is 103 dB(A). Figures 3.5.2-4 through 3.5.2-11 describe the octave band sound pressure levels of other sources that contribute to the total noise within the plant. The data presented in Figures 3.5.2-1 through 3.5.2-11 have been obtained from a noise survey report* as permission was not received for an in-plant noise survey.

3.5.3 Community Noise Levels

The can manufacturing plant operates on a three-shift basis and is located within an industrial area of a moderately large city. This city's population is 144,824 persons, with a population density of 17,159 persons per square mile. The average household income for residents is $10,198.00.

The can manufacturing plant is located in a heavily industrialized area. Figure 3.5.3-1 is a map of the community surrounding the can manufacturing plant. The residential area adjacent to the plant consists mainly of two- and three-family housing units. The residual noise levels (A-weighted) in the community (Locations 1 through 10), and on the property line of the plant (Locations a-j), for the weekend, weekday, and weeknight are given in Figure 3.5.3-1.

Though there are no major highways presently operating nearby, the streets are heavily travelled by bus, trucks, and automobiles.

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*"Noise Survey Report," Liberty Mutual Insurance Company, 12 June 1970.

The community noise is presented in Figures 3.5.3-2 through 3.5.3-11 as statistical noise spectra for Locations 1 through 10. These spectra are representative of what might be expected in an urban industrialized community. The noise of the can manufacturing plant is occasionally discernable at locations approximately one-half of a city block from the plant, but is masked much of the time by surface transportation noise.

Histograms of noise levels (A-weighted) for the same locations indicated above are presented in Figures 3.5.3-12 through 3.5.3-21.

The L_{10} A-weighted intrusive noise levels for each measurement location for the daytime, evening, and nighttime sampling periods are shown in Table 3.5.3-1.

The ambient noise levels at each measurement location in the community and on the property line are given in Figure 3.5.3-1.

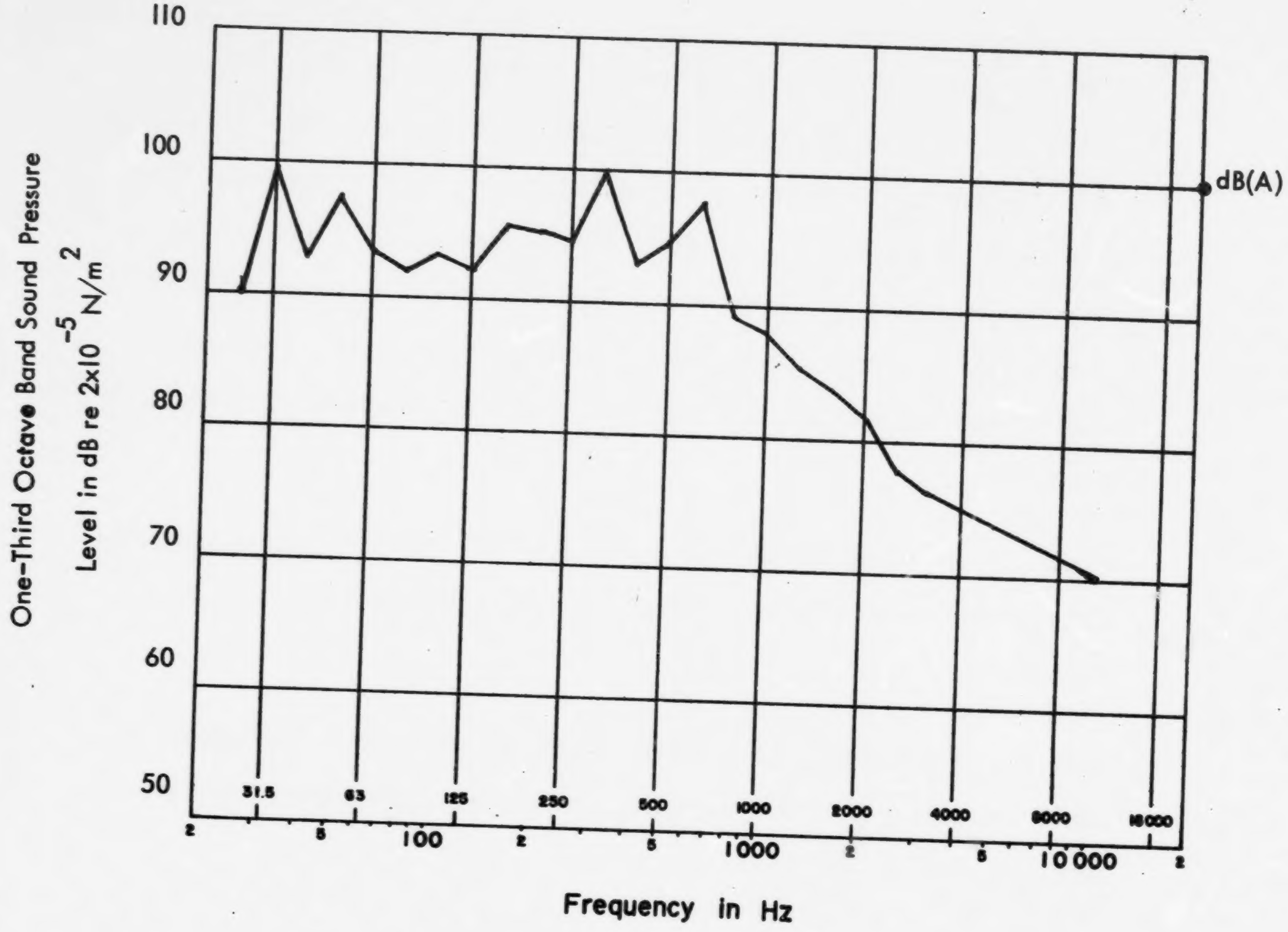


Figure 3.1.2-1 One-Third Octave Band Sound Pressure Levels Measured near the Inlet of an I.S. Machine Mold Cooling Fan in a Glass Manufacturing Plant.

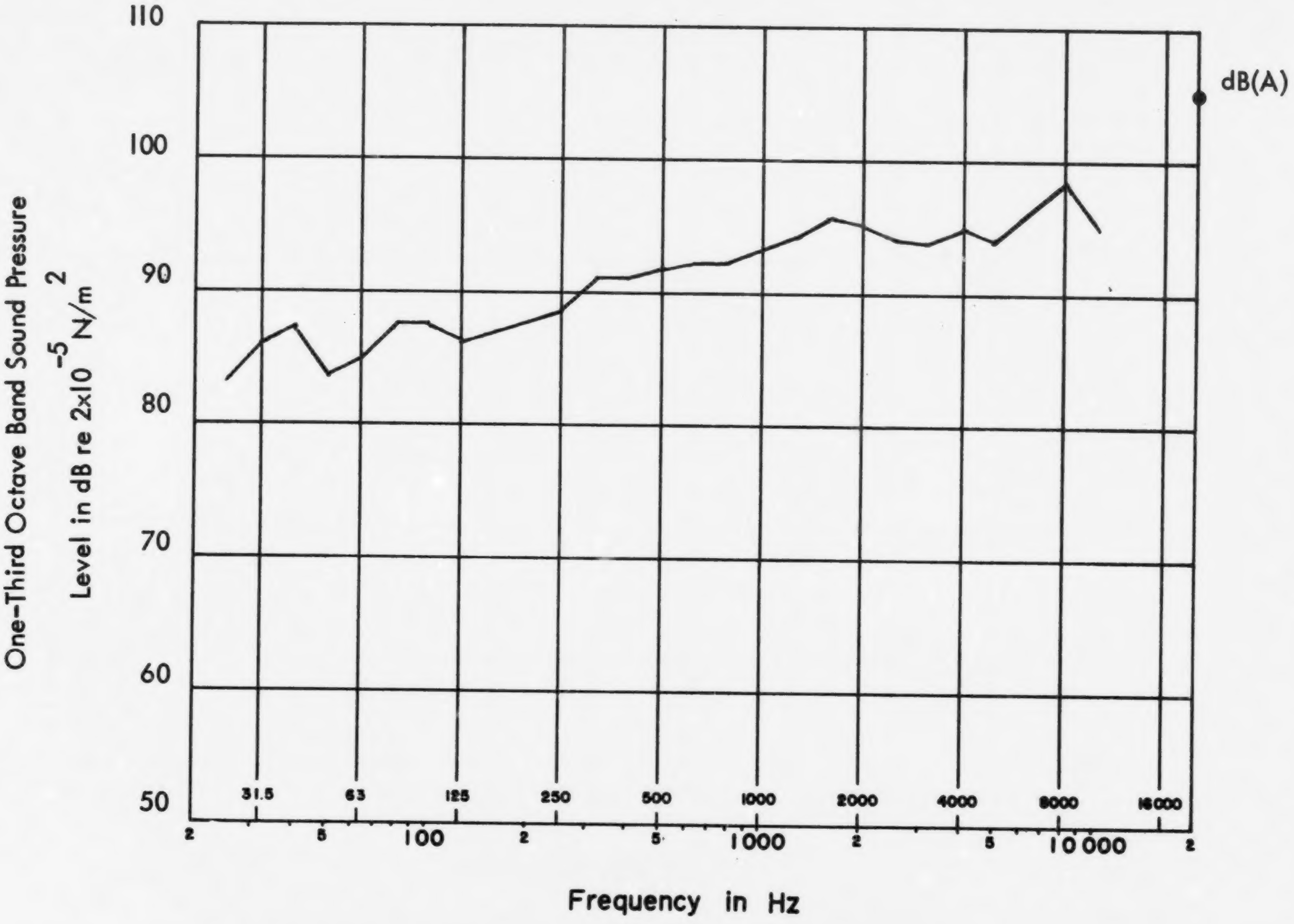


Figure 3.1.2-2. One-Third Octave Band Sound Pressure Levels Measured near an I.S. Machine Blow-Molding Die in a Glass Manufacturing Plant.

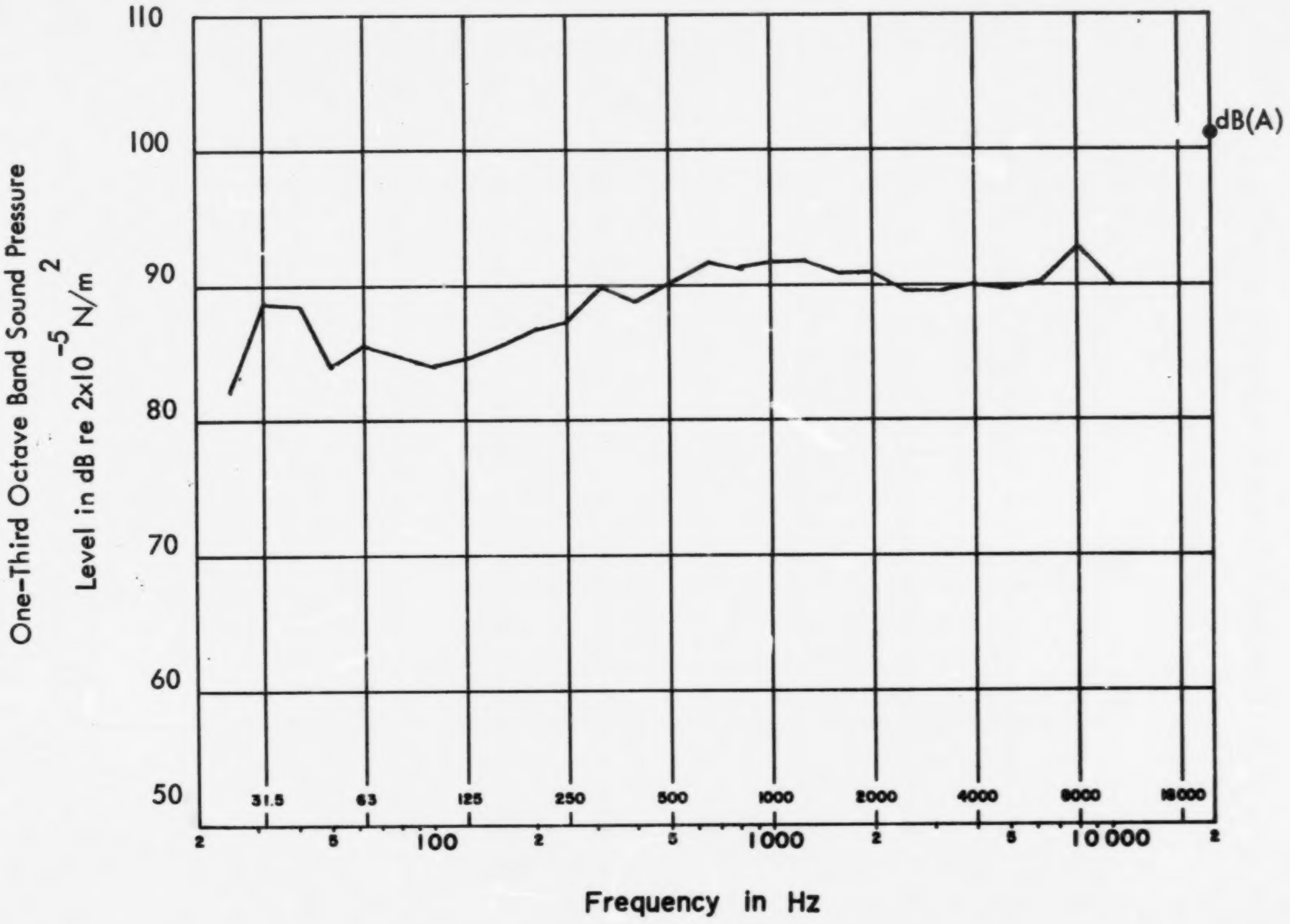


Figure 3.1.2-3. One-Third Octave Band Sound Pressure Levels Measured near One I.S. Machine in a Glass Manufacturing Plant.

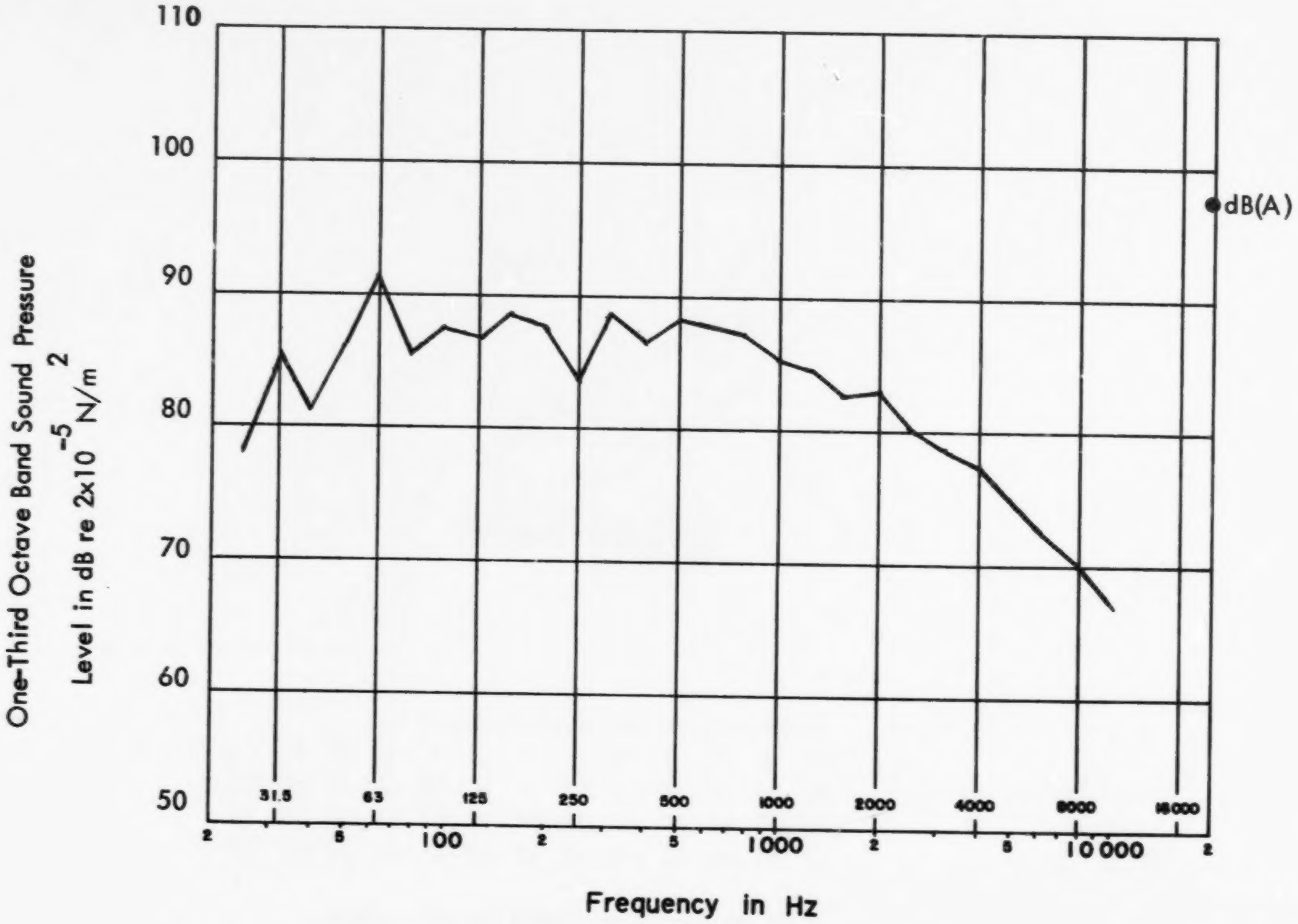
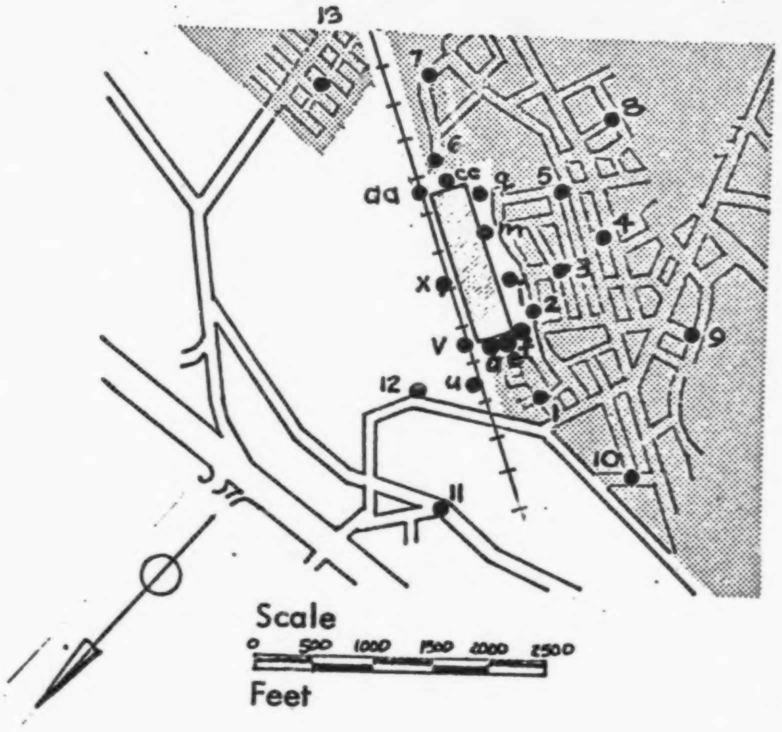


Figure 3.1.2-4. One-Third Octave Band Sound Pressure Levels Measured in the Air Compressor Room of the Glass Manufacturing Plant.


13
7
8
6
cc
q
5
aa
m
4
x
j
3
2
9
v
a
e
f
12
u
10
11
Scale
0 500 1000 1500 2000 2500
Feet

Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Weekend	46	54	45	39	41	43	-	-	48	41	41	51	43
Weekday	50	59	44	42	42	40	44	40	41	44	39	53	43
Weeknight	52	61	46	40	43	45	43	40	41	41	42	49	42

Plant Property Line Noise Levels in dB(A)

	a	e	f	j	m	q	cc	aa	x	v	u
Weekend	50	62	59	68	55	41	44	40	60	65	52
Weekday	49	64	61	68	59	49	50	49	66	68	55
Weeknight	51	64	63	69	58	48	41	46	61	65	54

Key

■	Industrial Noise Source
▨	Residential Area
┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 3.1.3-1. Glass Manufacturing Plant Community

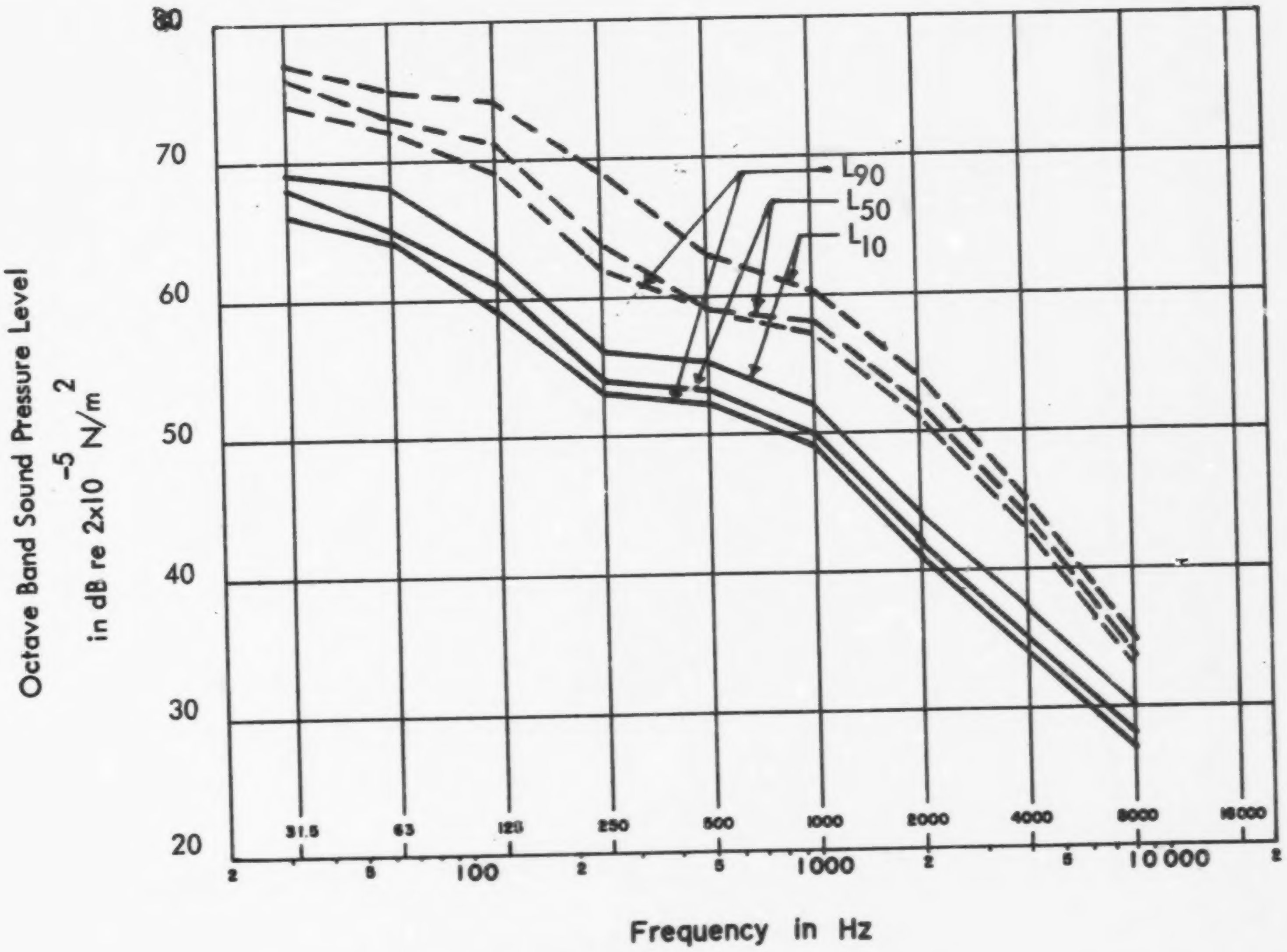


Figure 3.1.3-2. Glass Manufacturing Plant Location I.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

— — — Nighttime

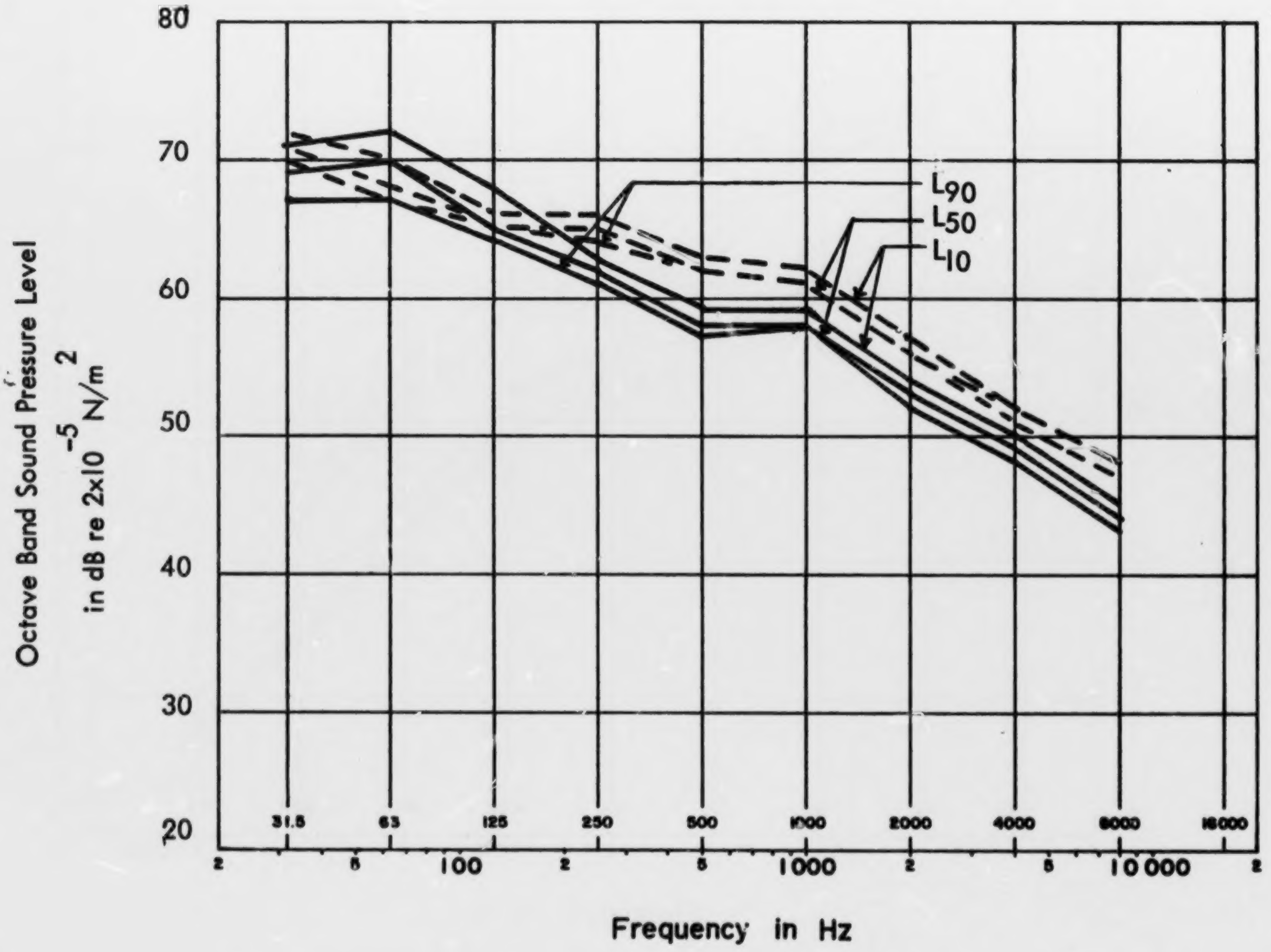


Figure 3.1.3-3. Glass Manufacturing Plant Location 2.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

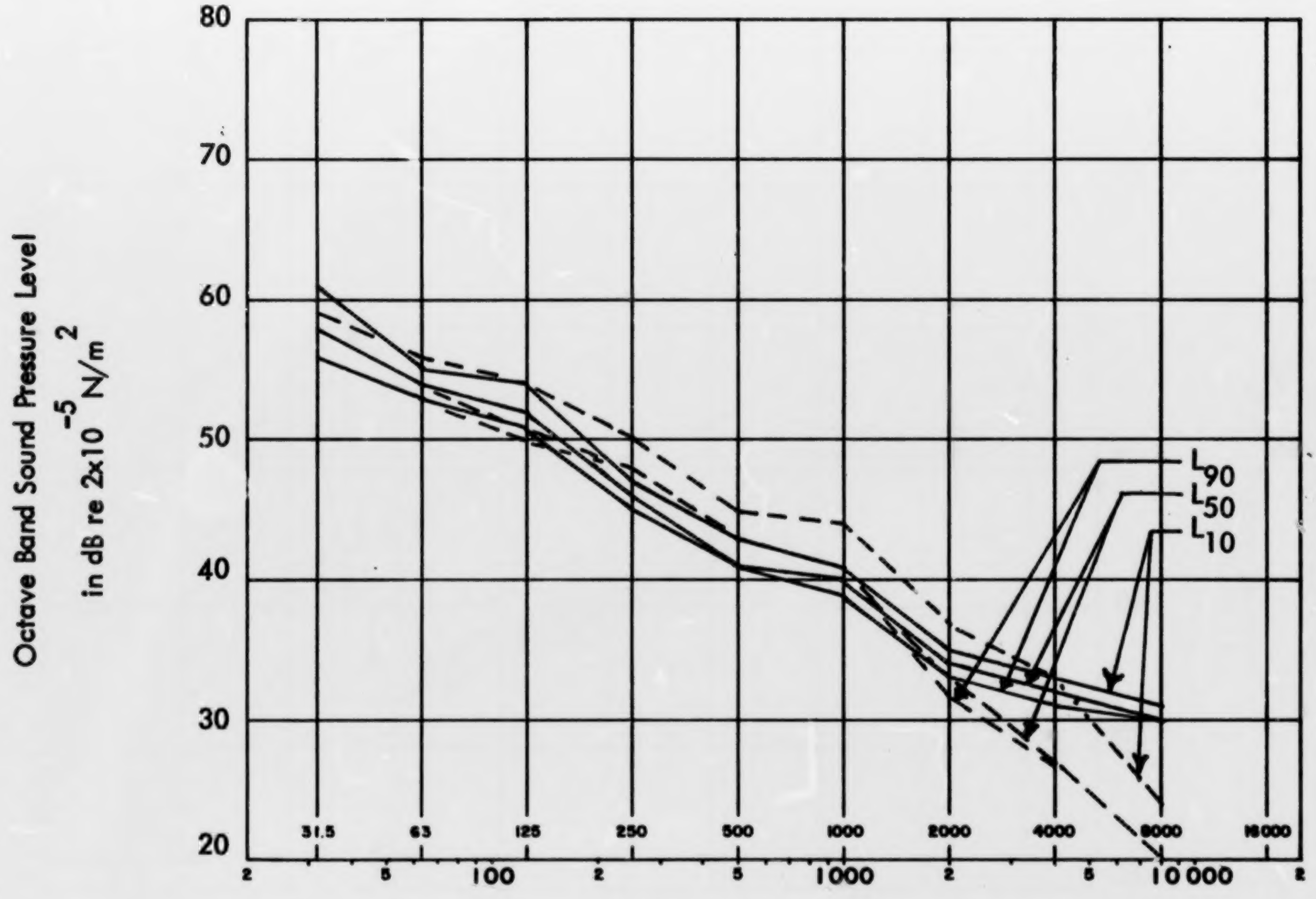


Figure 3.1.3-4. Glass Manufacturing Location 3

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

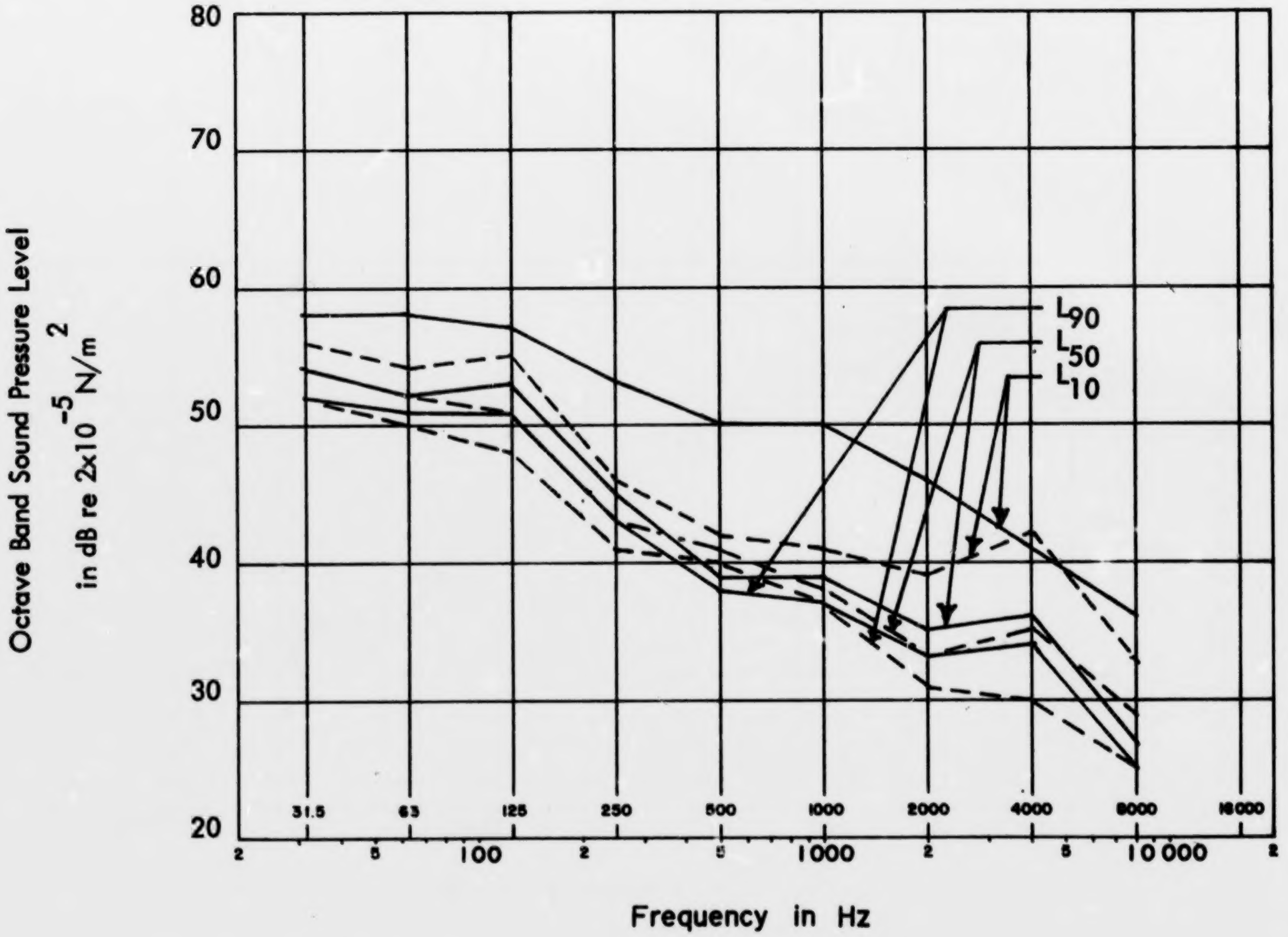


Figure 3.1.3-5. Glass Manufacturing Plant Location 4

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – Nighttime

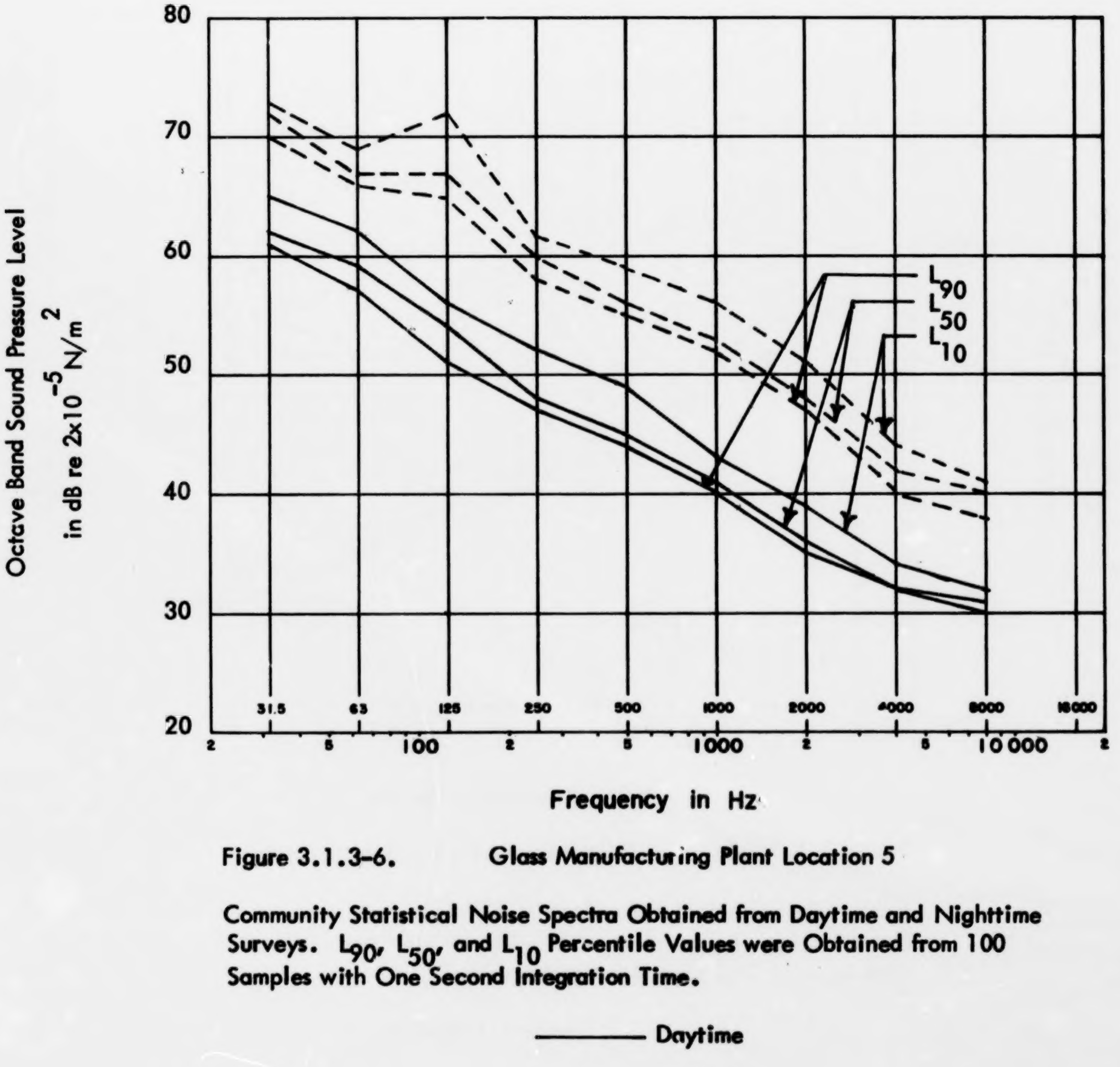


Figure 3.1.3-6. Glass Manufacturing Plant Location 5

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

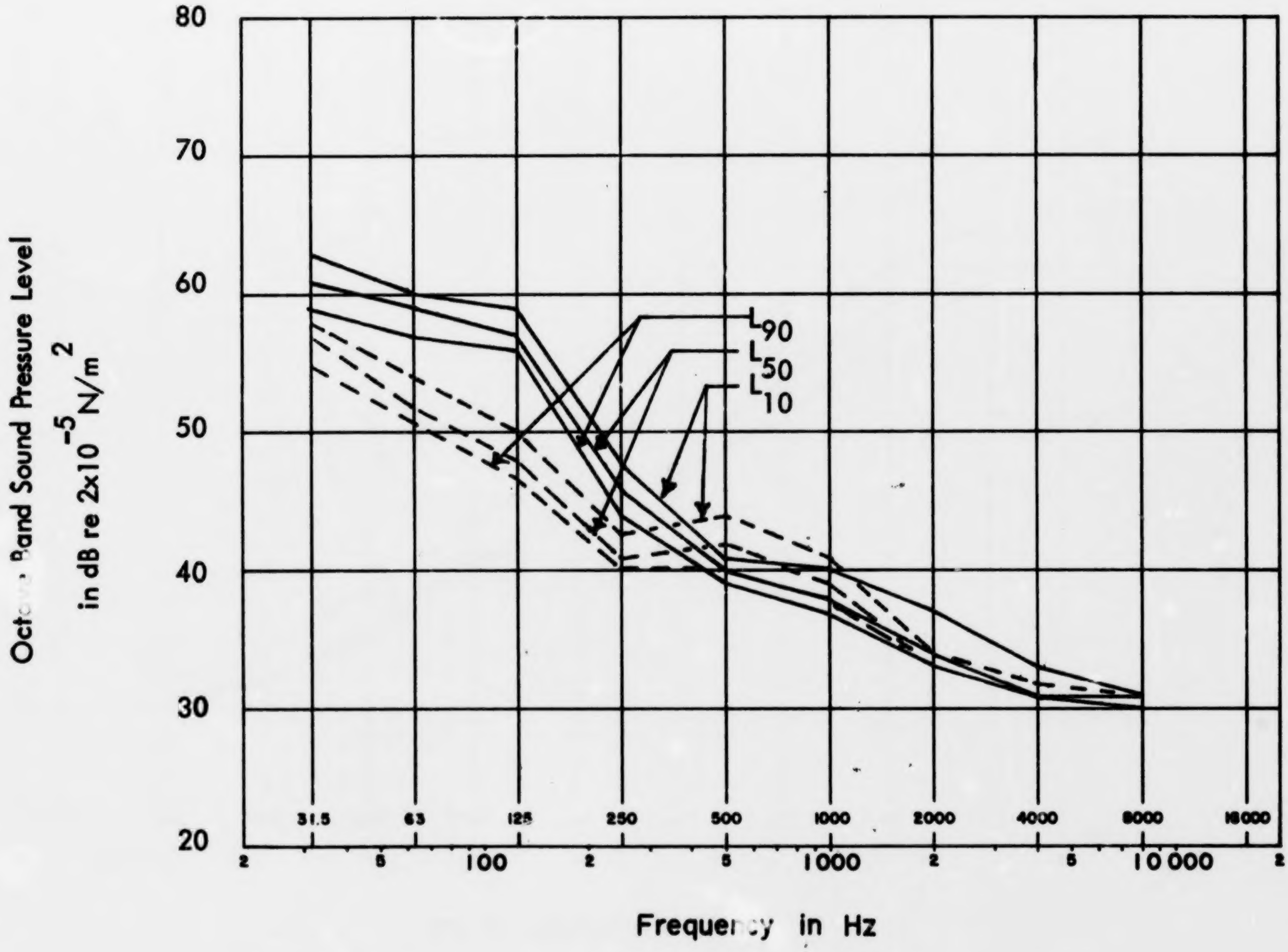


Figure 3.1.3-7. Glass Manufacturing Plant Location 6

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

- - - - - Nighttime

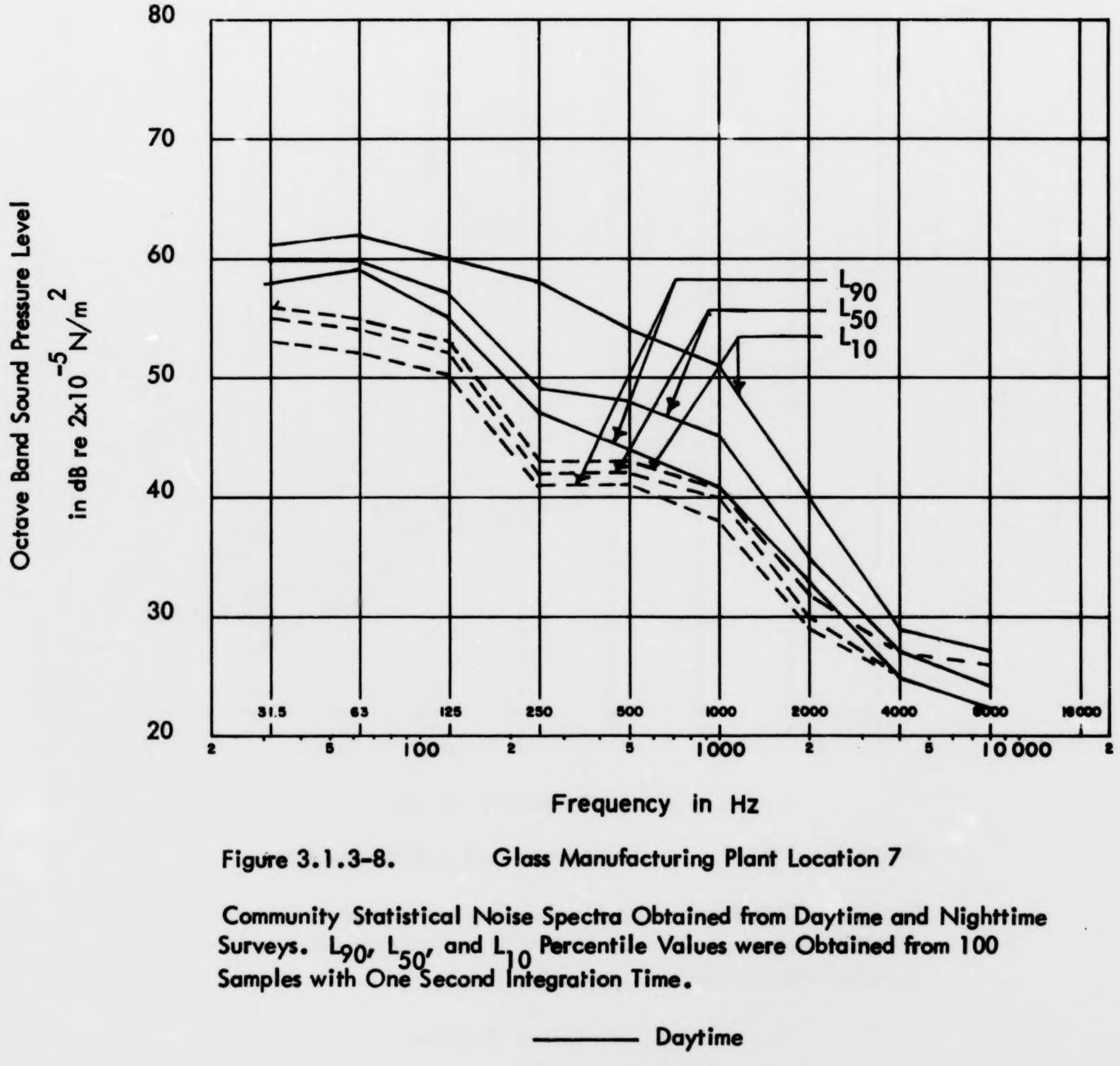


Figure 3.1.3-8. Glass Manufacturing Plant Location 7

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – Nighttime

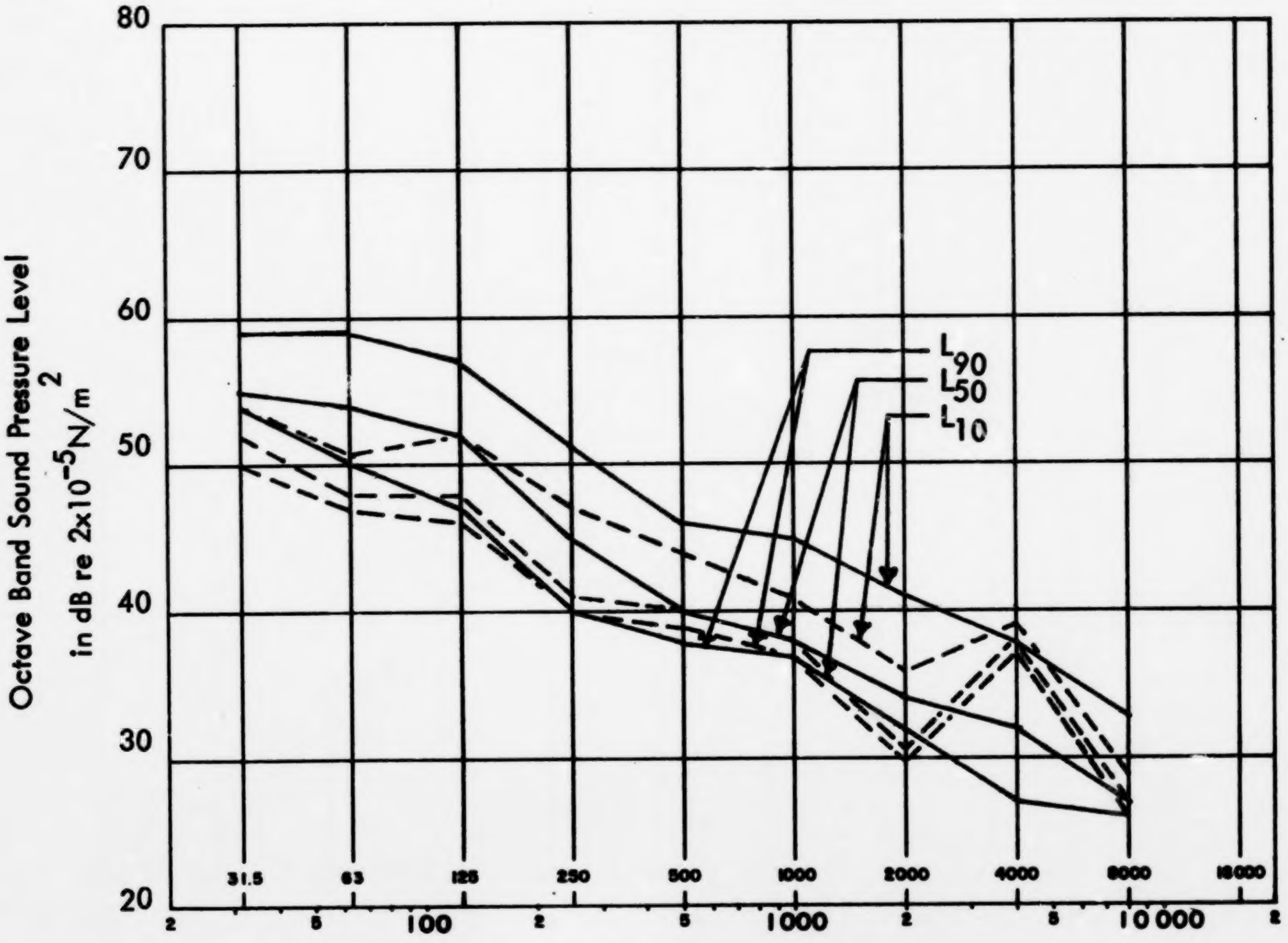


Figure 3.1.3-9. Glass Manufacturing Plant Location 8

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – – Nighttime

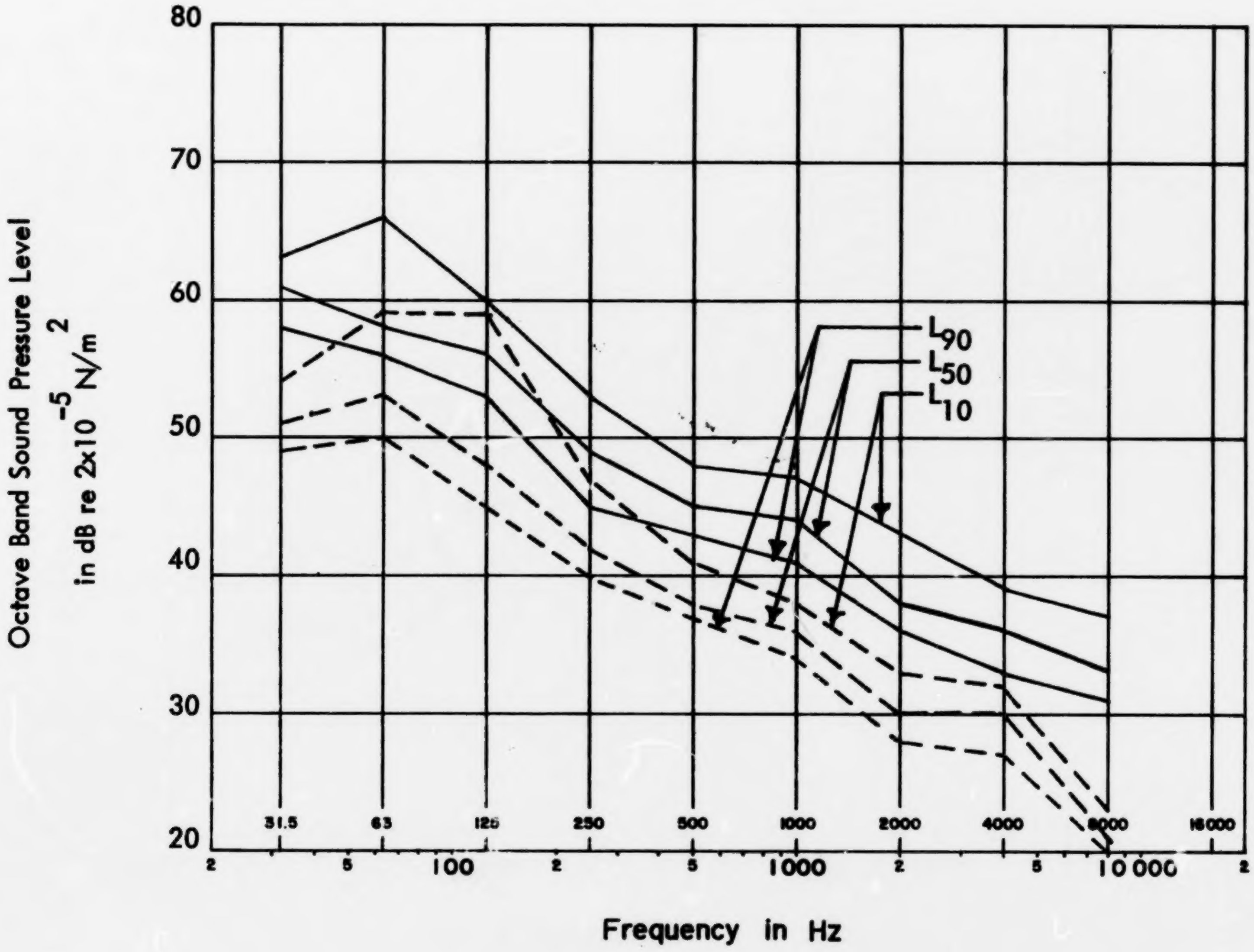


Figure 3.1.3-10. Glass Manufacturing Plant Location 9

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – – Nighttime

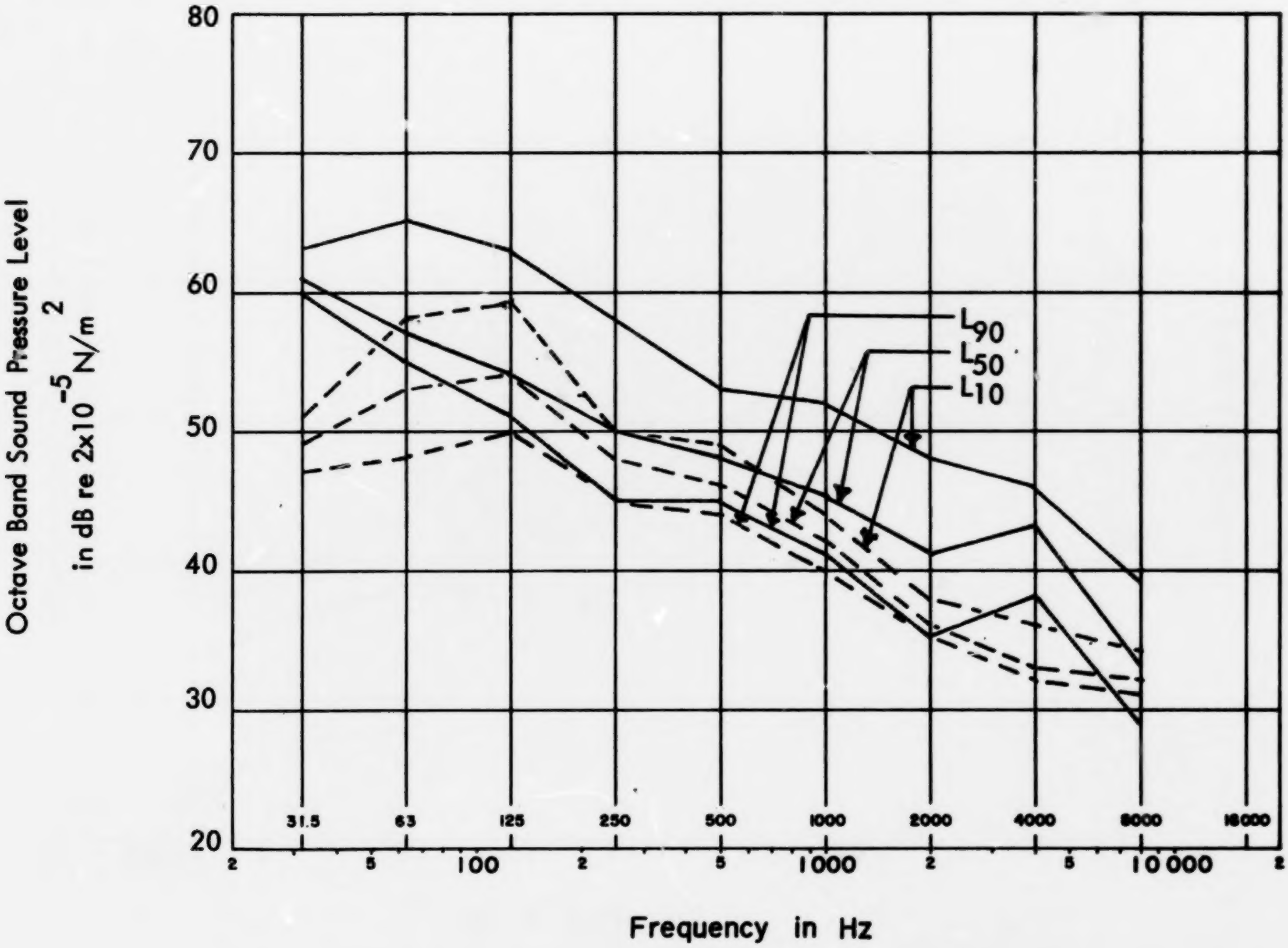


Figure 3.1.3-11. Glass Manufacturing Plant Location 10

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – – Nighttime

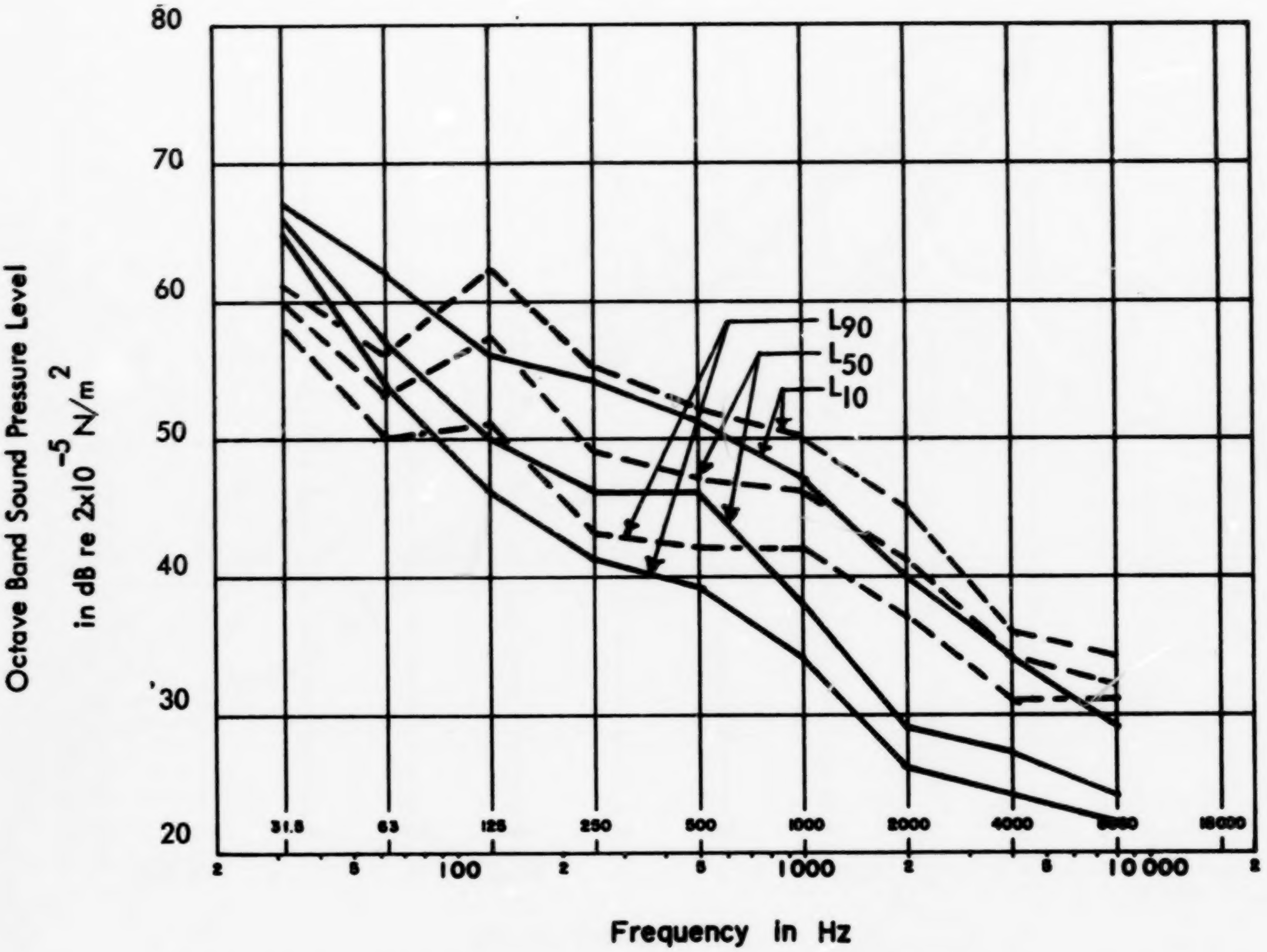


Figure 3.1.3-12. Glass Manufacturing Plant Location II.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

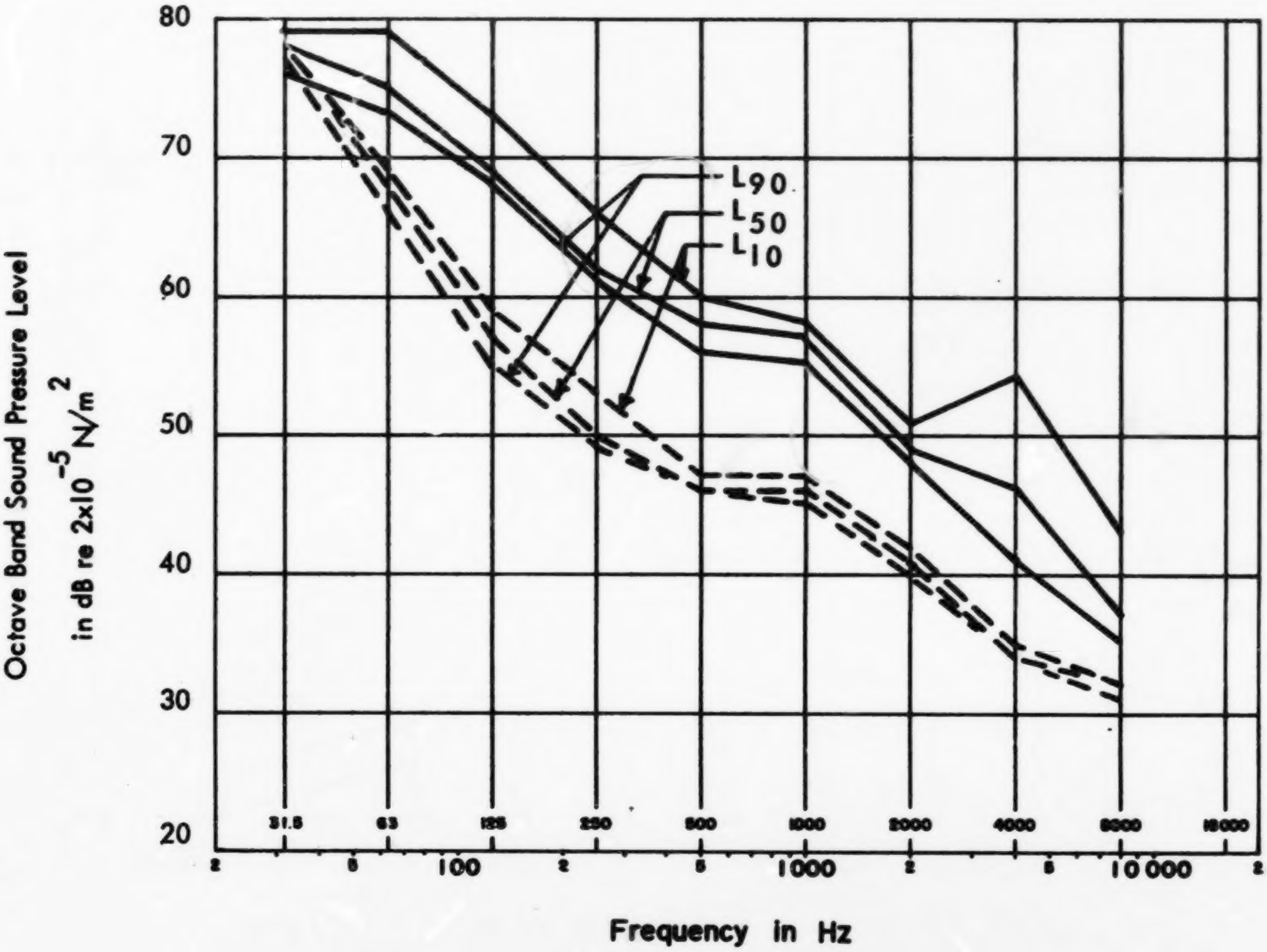


Figure 3.1.3-13. Glass Manufacturing Plant Location 12.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

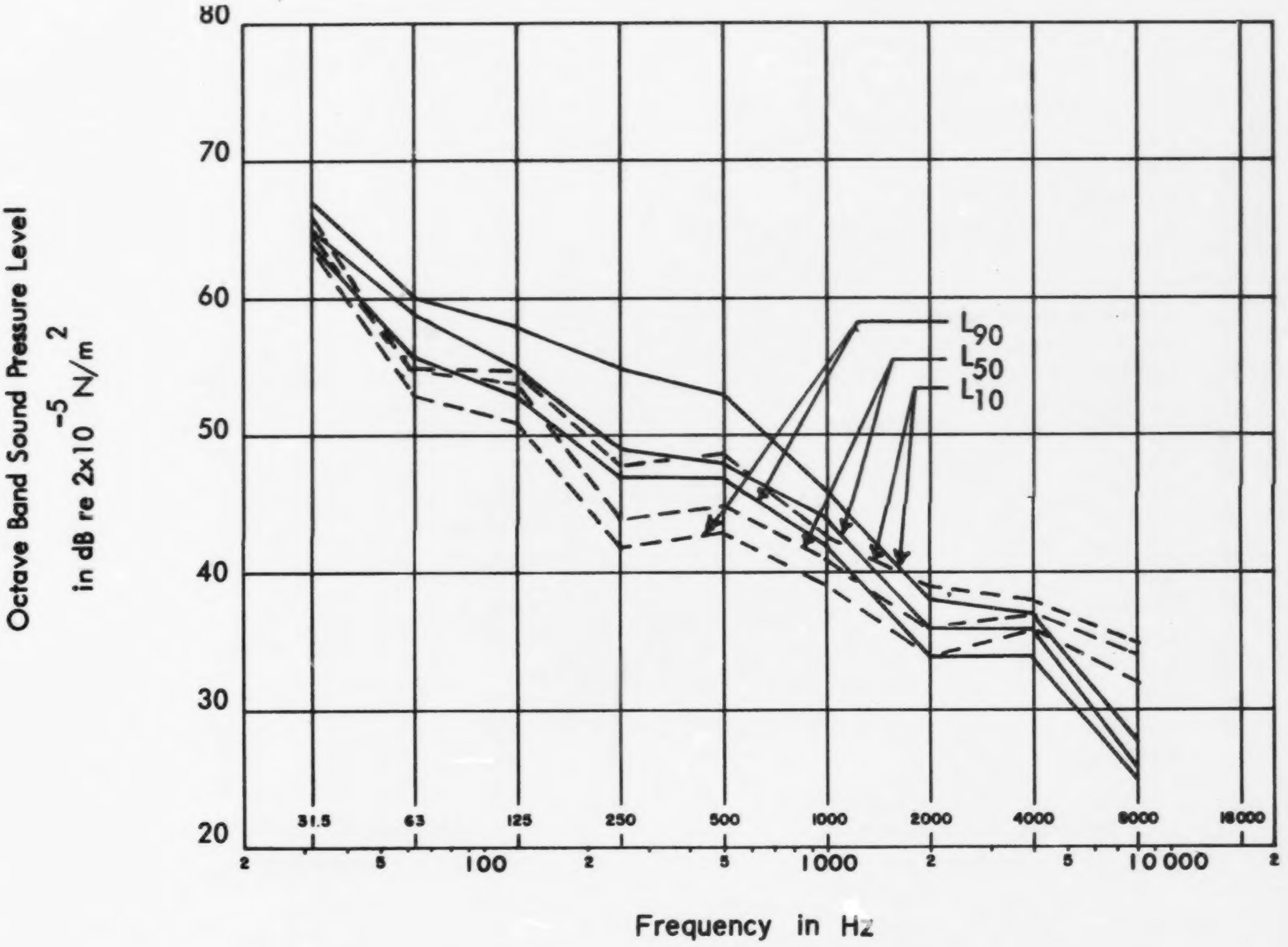


Figure 3.1.3-14. Glass Manufacturing Plant Location 13

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———————— Daytime

– – – – – – Nighttime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40 **
41 *
42
43
44 *
45 ***
46
47 *
48 **
49 *************
50 *******
51 *****
52 ****
53 ***
54 *
55 **
56 *
57
58
59 **
60 **
61
62
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40
41
42
43
44 *
45
46
47 ****
48 ***
49 **
50 *****
51 ****************
52 *******
53 ***
54 *
55 *
56 *
57 *
58 *
59 **
60
61
62
63
64 **
65
```

Number of Occurrences
Nighttime

Figure 3.1.3.15. Glass Manufacturing Plant Location 1.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5} N/m^2$

```
60
61 ***
62 ********************
63 ******************
64 ******
65 *
66
67 *
68 *
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5} N/m^2$

```
60
61
62
63
64 *
65 *******************
66 **************************
67 *
68 **
69 *
70
```

Number of Occurrences
Nighttime

Figure 3.1.3-16. Glass Manufacturing Plant Location 2.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40
41
42
43
44 *******
45 ******************************
46 ***********
47 **
48
49
50
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40 **
41
42
43
44
45
46
47
48 *
49 *****************************
50 ******************
51
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.1.3-17. Glass Manufacturing Plant Location 3.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40
41 *
42 **
43 ********
44 ***************
45 ********
46 ******
47 **
48 *****
49
50
51
52 *
53
54 *
55 *
56
57
58
59
60
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
35
36
37
38
39 *
40 ****
41 **************************************
42 *******
43
44
45
```

Number of Occurences
Nighttime

Figure 3.1.3-18. Glass Manufacturing Plant Location 4.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40 **
41 ****
42 *
43
44
45
46 *********
47 *****************
48 **
49 ***********
50 ****
51
52
53
54
55
```

Number of Occurrences
Daytime

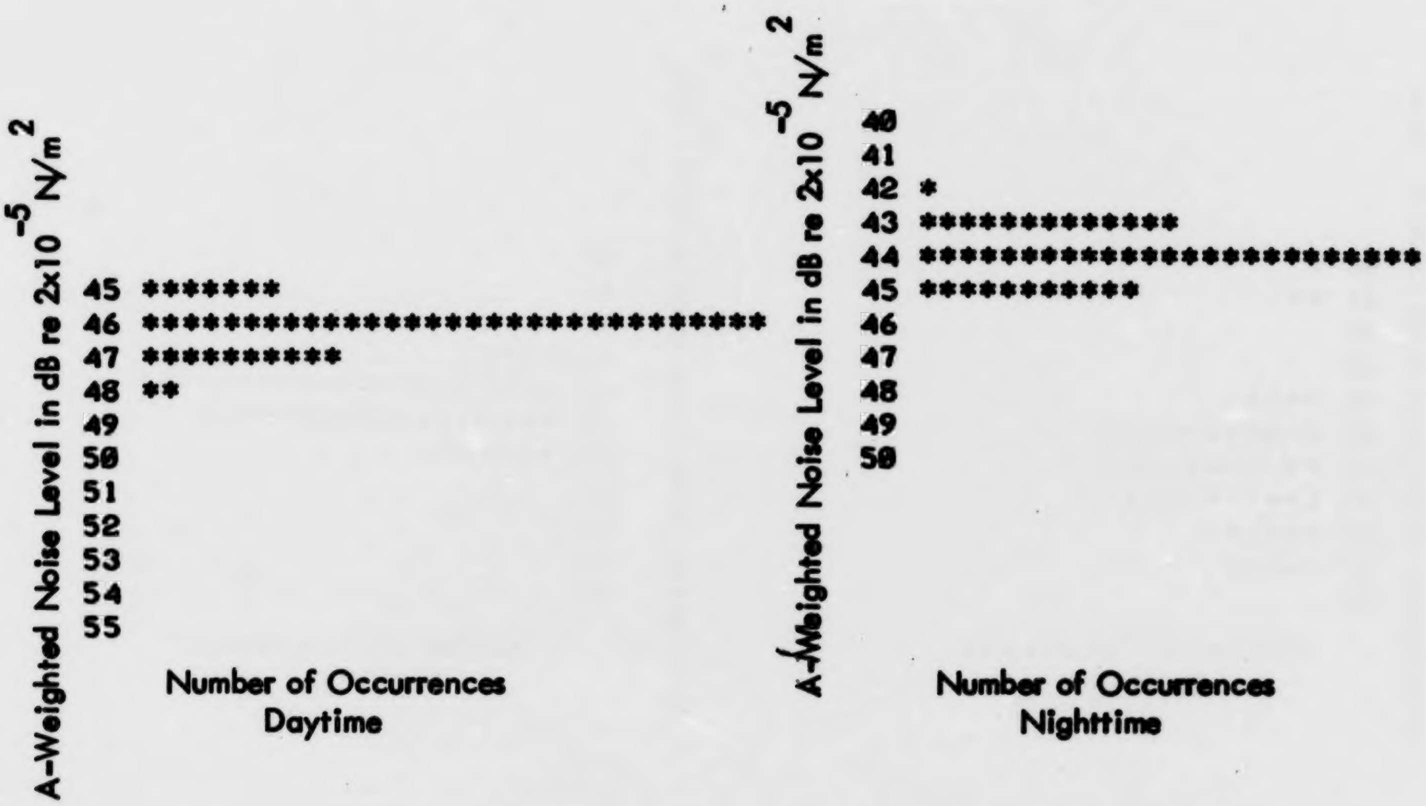
A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40
41
42
43
44 **
45 *************
46 *****************
47 ***********
48 *****
49 **
50
```

Number of Occurrences
Nighttime

Figure 3.1.3-19. Glass Manufacturing Plant Location 5.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.



```
45 *******
46 *******************************
47 **********
48 **
49
50
51
52
53
54
55
```

```
40
41
42 *
43 *************
44 *************************
45 ***********
46
47
48
49
50
```

Figure 3.1.3-20. Glass Manufacturing Plant Location 6.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
40 *
41 **
42
43
44 ****
45 ***********
46 ***********
47 **********
48 ******
49 *****
50

    Number of Occurrences
          Daytime
```

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
40
41
42
43 ****
44 *********************
45 ******************
46 *******
47
48
49
50

    Number of Occurrences
          Nighttime
```

Figure 3.1.3-21. Glass Manufacturing Plant Location 7.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
40
41 ***********
42 *****************
43 **************
44 ****
45
46
47
48
49 *
50 *
51
52 **
53
54
55
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
40
41
42 *******
43 *********************
44 ***************
45 *****
46 **
47
48
49
50
```

Number of Occurrences
Nighttime

Figure 3.1.3-22. Glass Manufacturing Plant Location 8.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40 **
41 *
42 *********
43 ***************
44 *********
45 ******
46 ***
47 *
48 *
49
50
51
52
53
54
55
56
57
58
59
60
61
62 **
63
64
65
66 *
67
68
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46 ********
47 **************************
48 ******
49 **
50 *
51 ****
52 *
53 *
54 *
55
```

Number of Occurrences
Nighttime

Figure 3.1.3-23. Glass Manufacturing Plant Location 9.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40 **
41 ****
42 **
43 *
44
45
46 ********
47 ****
48 ******
49 ********
50 *******
51 **
52 *
53 *
54
55
56
57 **
58 *
59
60
61 *
62
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40 **
41
42
43
44
45 **
46 **
47 *********
48 ******************
49 ************
50 *****
51
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.1.3-24. Glass Manufacturing Plant Location 10.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
35
36
37
38
39 ***
40 ***********
41 *******
42 *****
43 ***
44 **
45 *
46 **
47 ***
48 ***
49 **
50 ****
51
52 *
53
54
55
56 *
57
58 *
59 *
60
```

NOT REPRODUCIBLE

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
35
36
37
38
39 *
40 *
41 *
42 **
43
44 *
45
46 ****
47 ***
48 ******
49 ****
50 ***
51 ****
52 ********
53 ****
54 ***
55
56
57
58 *
59 *
60 *
61
62
63
64
65
66
67
68
69
70
71
72 **
73
```

Number of Occurrences
Nighttime

Figure 3.1.3-25. Glass Manufacturing Plant Location 11.

Noise Level (A-Weighted) Histogram 50 Samples Four Second integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
40 *
41 ***
42 *
43 *
44 *
45 *
46 **
47 ****
48 **
49 ****
50 **
51
52 *
53
54 ***
55 *
56 ***
57 ***
58 ***
59 ***
60 **
61 *****
62 *
63 *
64 *
65
66
67
68
69 *
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
40 *
41 **
42
43
44 *
45
46
47
48 *
49 ******
50 **********
51 ********
52 ****
53 **
54 ***
55 *
56
57 *
58
59 *
60
61 *
62 **
63 *
64
65 *
66 ***
67
68
69
70 *
```

Number of Occurrences
Nighttime

Figure 3.1.3-26. Glass Manufacturing Plant Location 12.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40 **********
41 ********************
42 *********
43 ******
44 ****
45 *
46
47
48
49
50
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40
41
42
43
44 **
45 ********
46 *************
47 ***********
48 ***********
49 *****
50
```

Number of Occurrences
Nighttime

Figure 3.1.3-27. Glass Manufacturing Plant Location 13.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

Table 3.1.3-1 - Intrusive (L_{10}) Noise Level (A-Weighted) Observed at Glass Manufacturing Plant Community Locations During Day, Evening, and Nighttime Sampling Periods

	Noise Level dB(A)		
Location	Day	Evening	Night
1	56	53	66
	56	56	52
	54		
2	61	61	60
	59	61	66
	63		
3	51	46	48
	45		50
	46		
4	51	45	42
	54	48	42
	46		
5	44	49	47
	42		48
	50		
6	43	42	45
	47	62	45
7	55	45	46
	49	45	
	48		
8	50	44	44
	45	47	45
	44		
9	45	46	46
	52		46
	45		50
10	55	48	58
	48		48
	57		50
11	52		41
	51		54
			54
12	55		52
	64		53
	63		
13	53		44
	46		41
	44		49

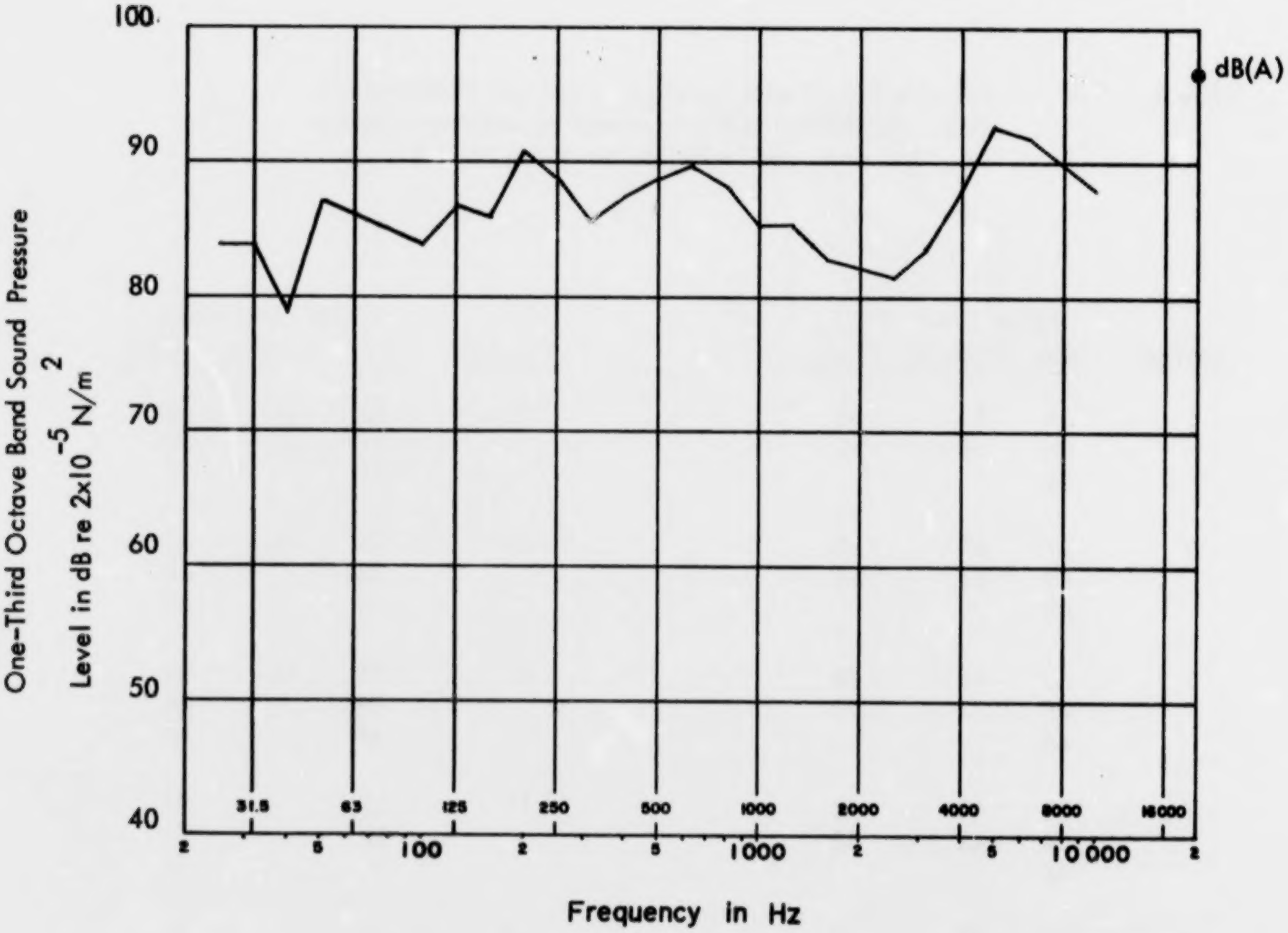


Figure 3.2.2-1. One - Third Octave Band Sound Pressure Levels Measured Near a Petrochemical Furnace in an Oil Refinery.

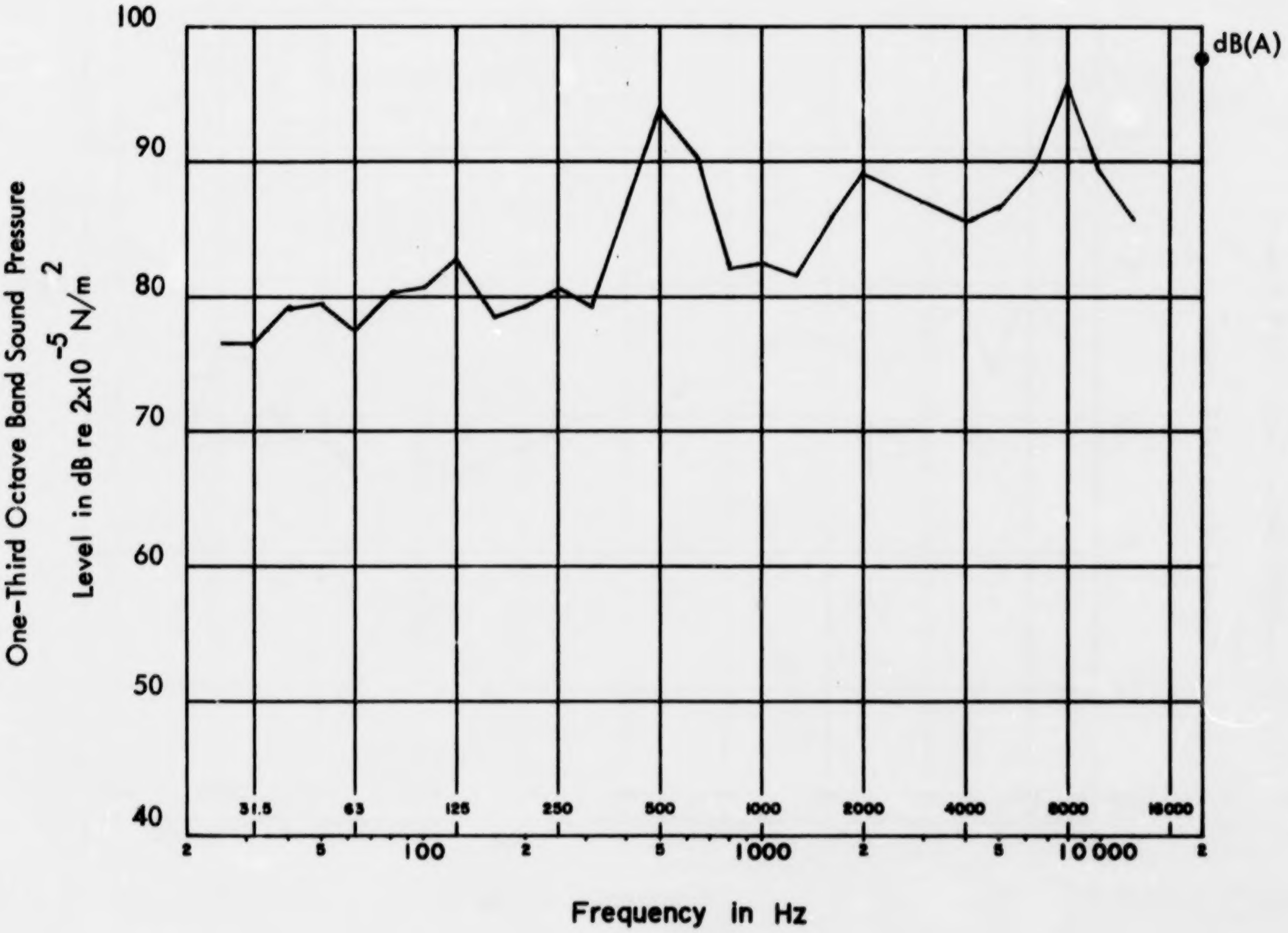


Figure 3.2.2-2. One-Third Octave Band Sound Pressure Levels Measured Near a Hydrogen Centrifugal Compressor Station in an Oil Refinery.

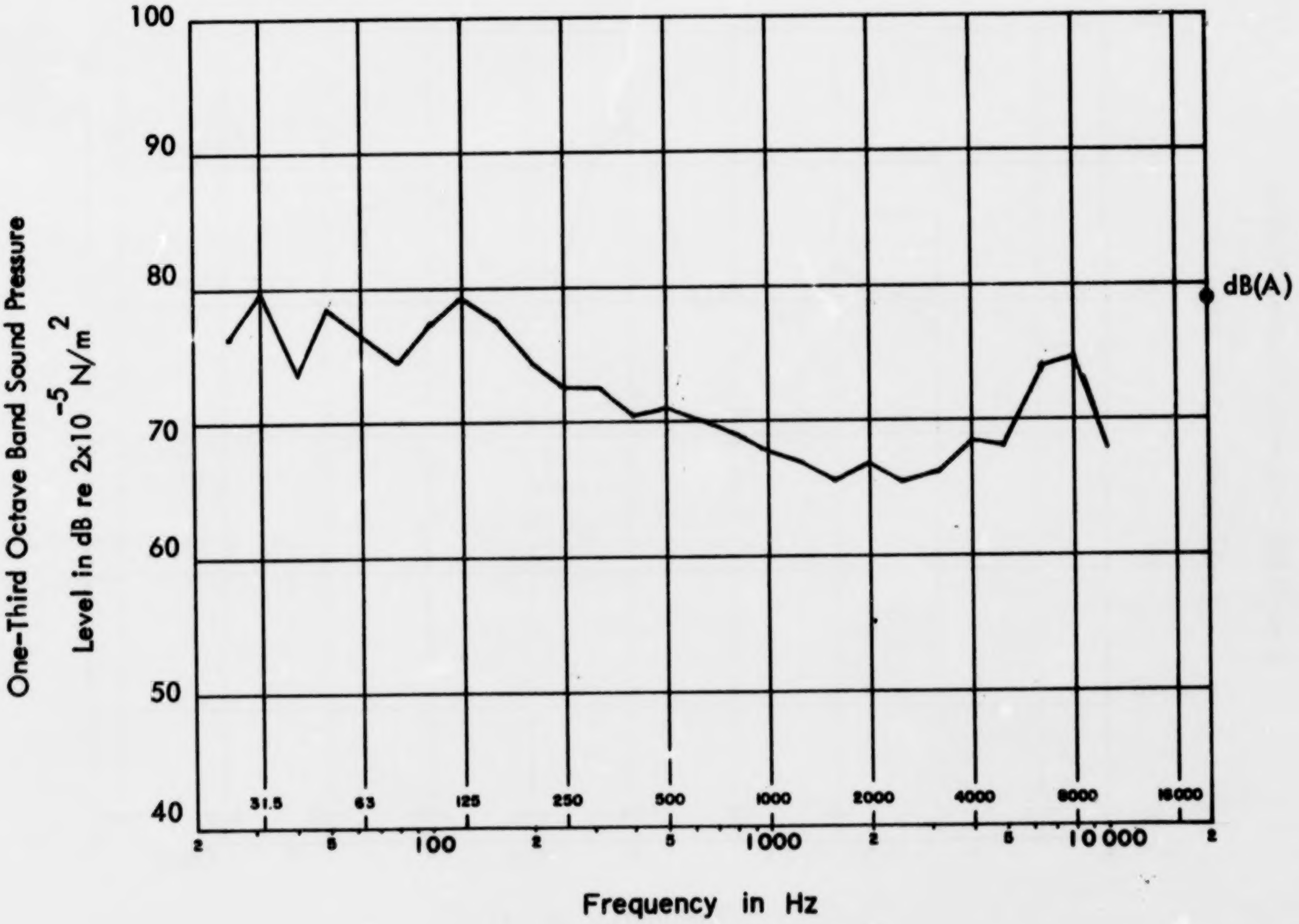


Figure 3.2.2-3. One-Third Octave Band Sound Pressure Levels Measured Near a Fin Fan in an Oil Refinery.

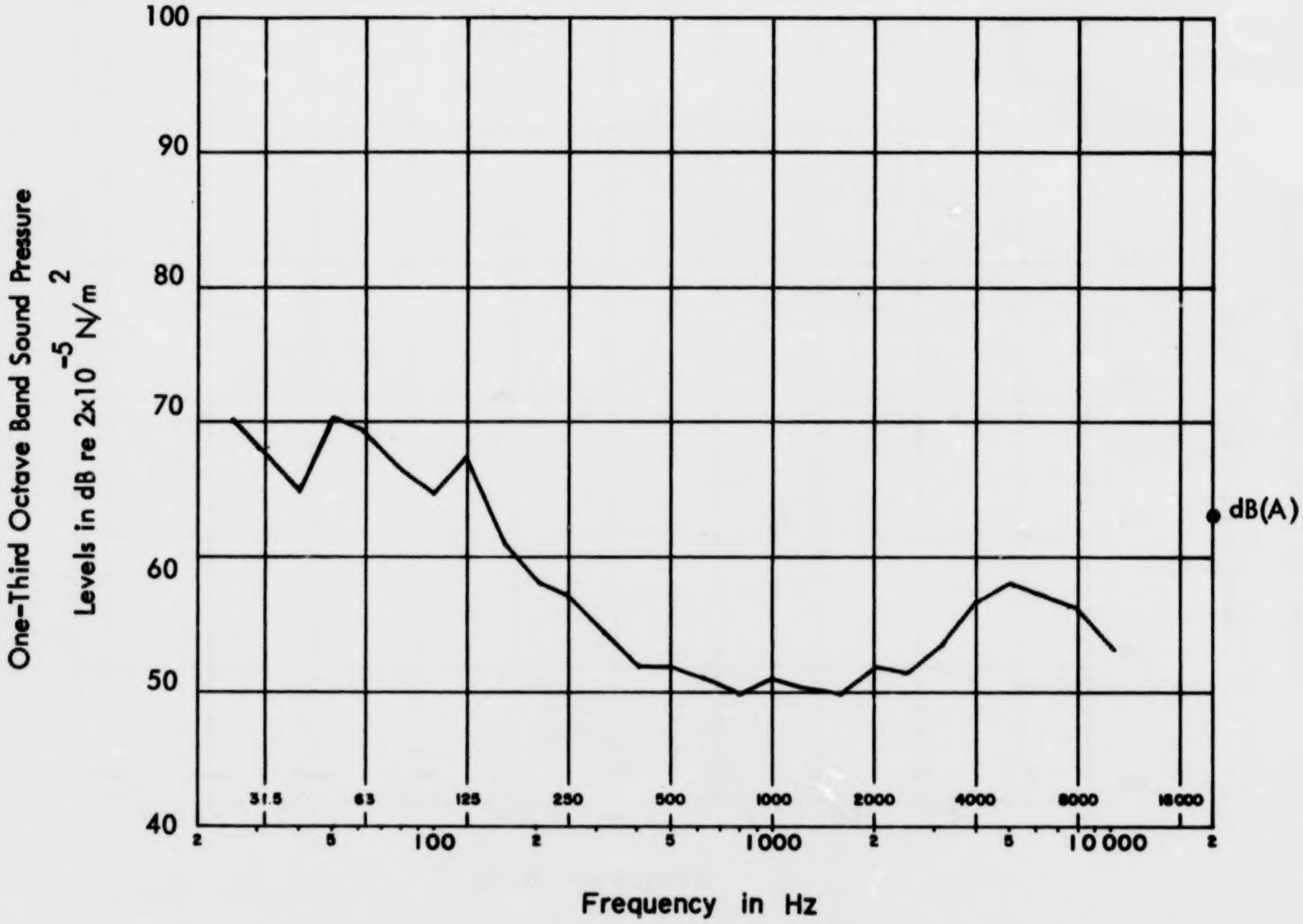


Figure 2.3.2-4. One-Third Octave Band Sound Pressure Levels Measured in Storage Tank Area in an Oil Refinery.

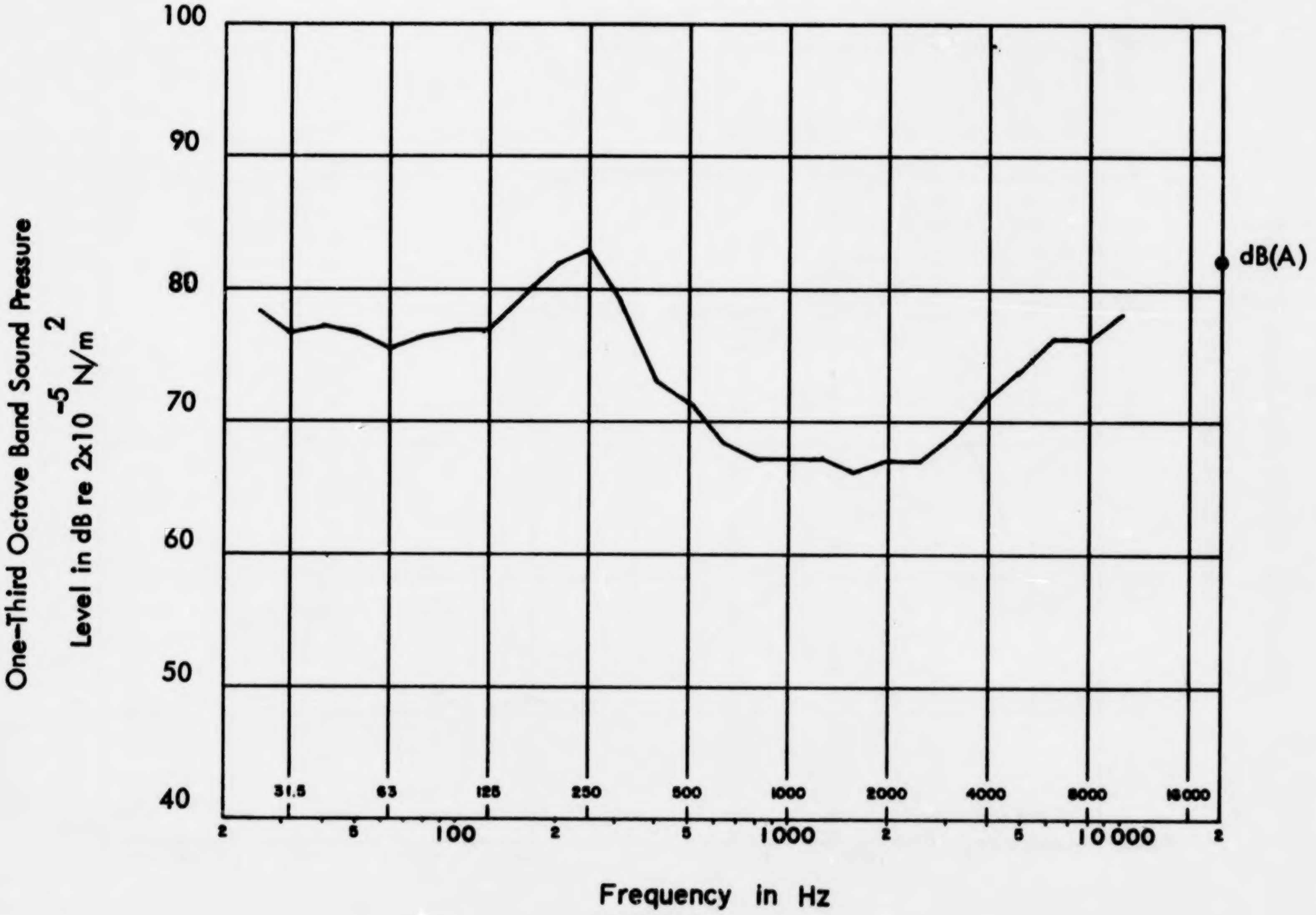


Figure 3.2.2-5. One-Third Octave Band Sound Pressure Levels Measured Between Two Flare Stacks and Near Furnaces; (Pentone Units) in an Oil Refinery.

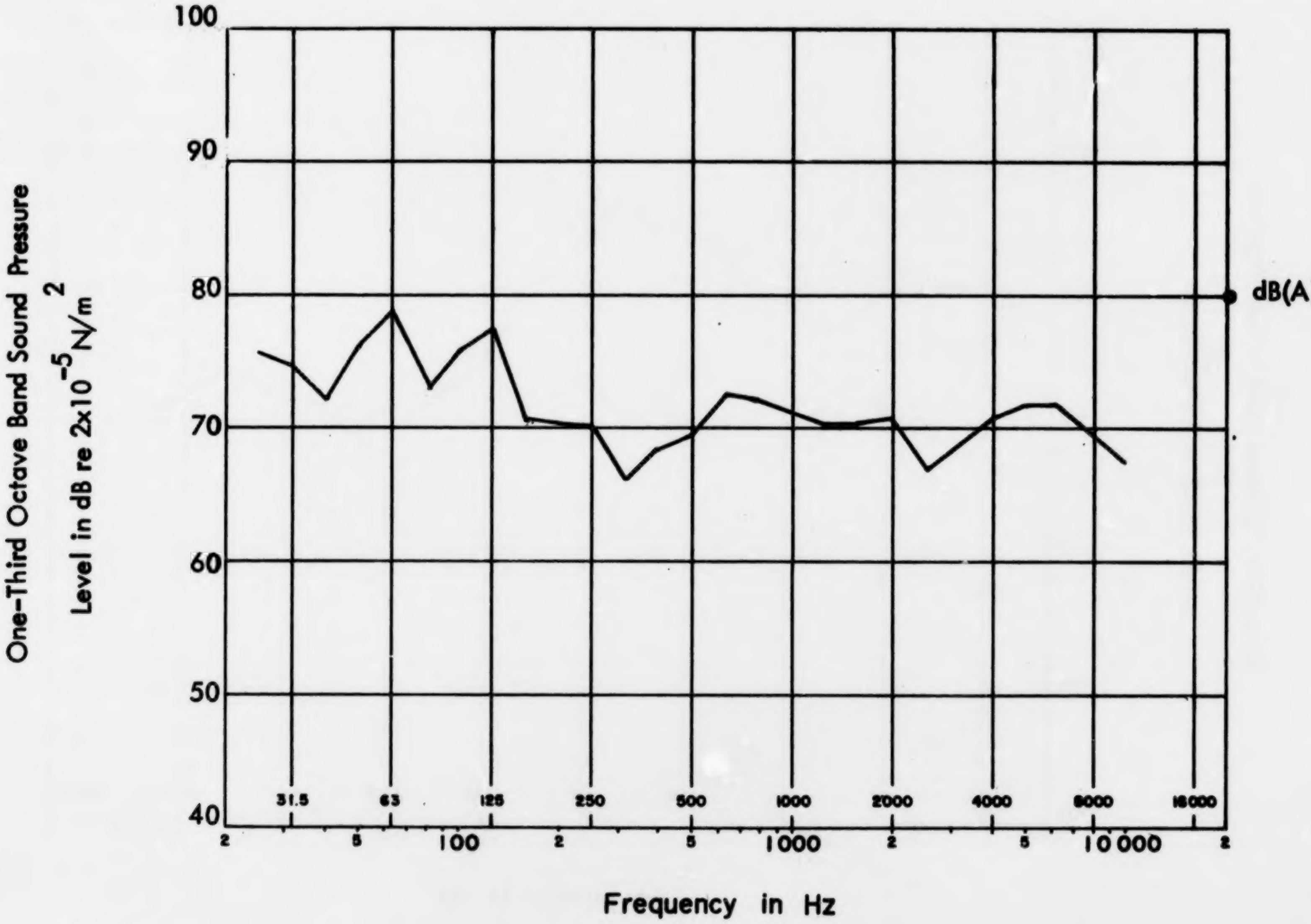


Figure 3.2.2-6. One-Third Octave Band Sound Pressure Levels Measured Near a Catalytic Cracking Unit in an Oil Refinery.

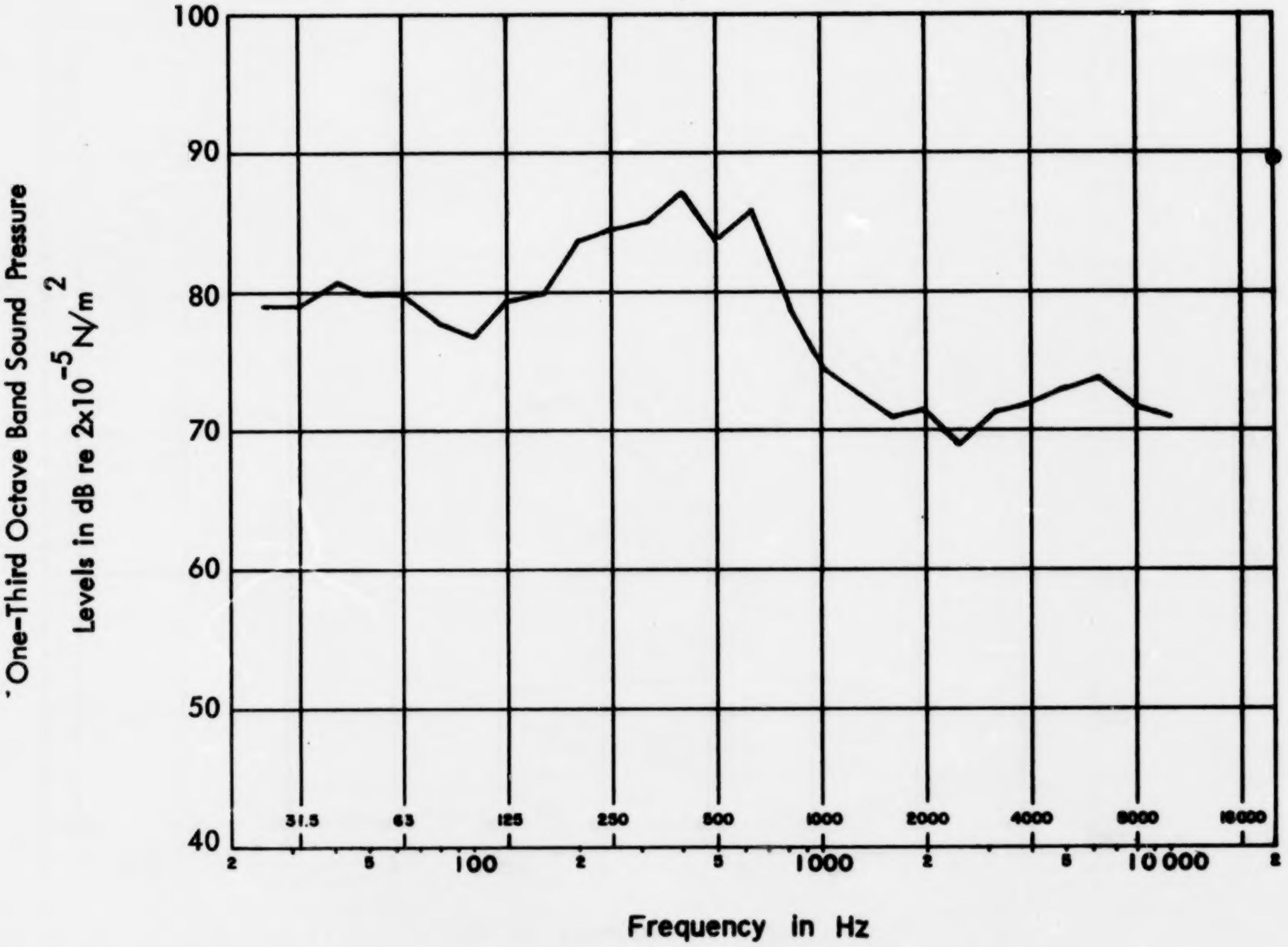


Figure 3.2.2-7. One-Third Octave Band Sound Pressure Levels Measured Near a Cabin-Type Furnace (Alcorn) in an Oil Refinery.

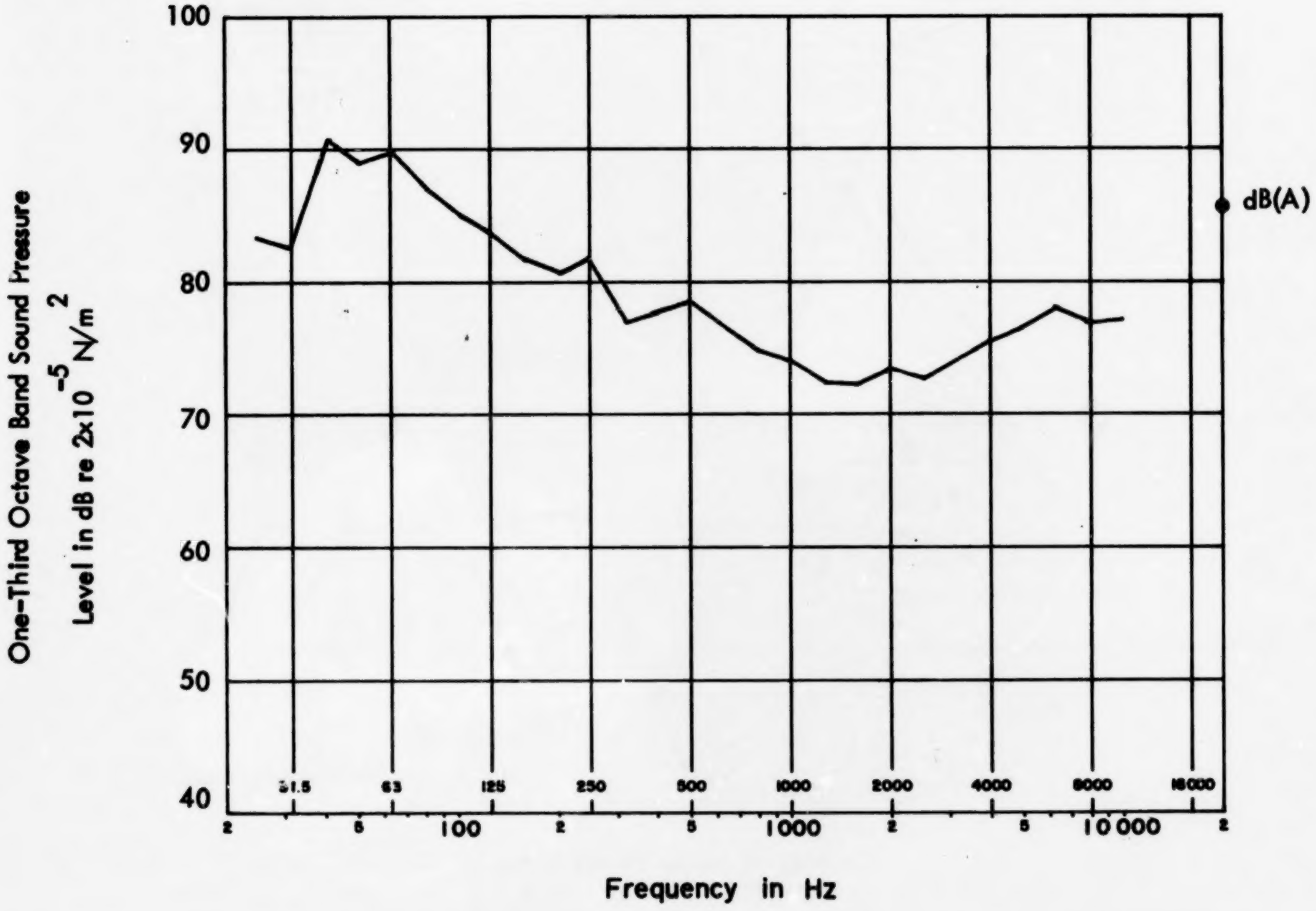
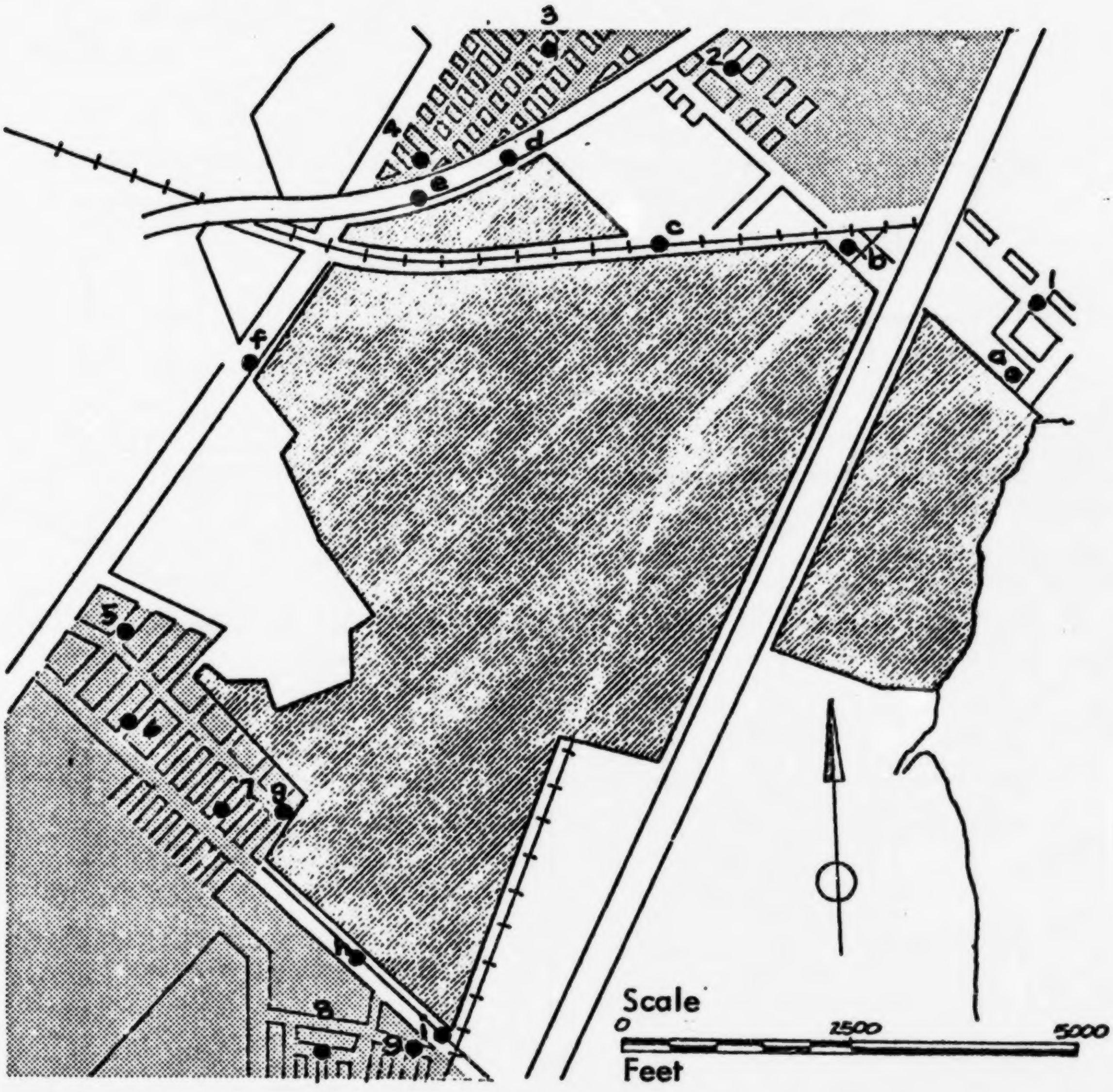


Figure 3.2.2-8. One-Third Octave Band Sound Pressure Levels Measured Between Fin Fan Array and Cabin-Type Furnace in an Oil Refinery.



Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8	9
Weekend	59	49	52	55	50	50	50	48	51
Weekday	63	52	50	56	48	51	54	47	50
Weeknight	60	51	51	50	47	49	59	47	49

Plant Property Line Noise Levels in dB(A)

	a	b	c	d	e	f	g	h	i
Weekend	55	71	60	60	60	55	54	52	56
Weekday	63	68	60	62	64	63	51	52	53
Weeknight	58	67	59	59	62	61	49	50	54

Key

▨	Industrial Noise Source
▒	Residential Area
┼┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 3.2.2-1. Oil Refinery Community

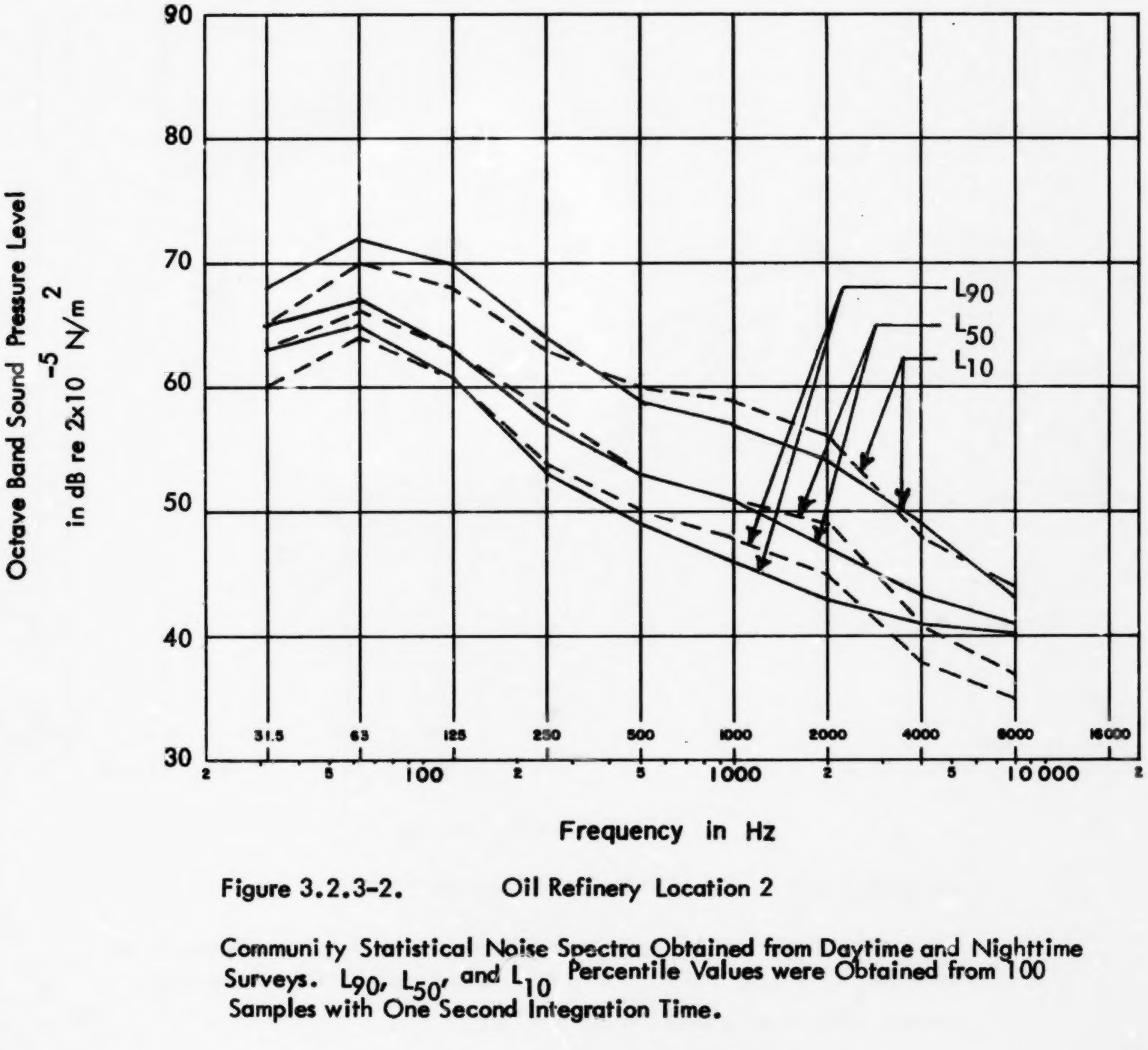


Figure 3.2.3-2. Oil Refinery Location 2

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

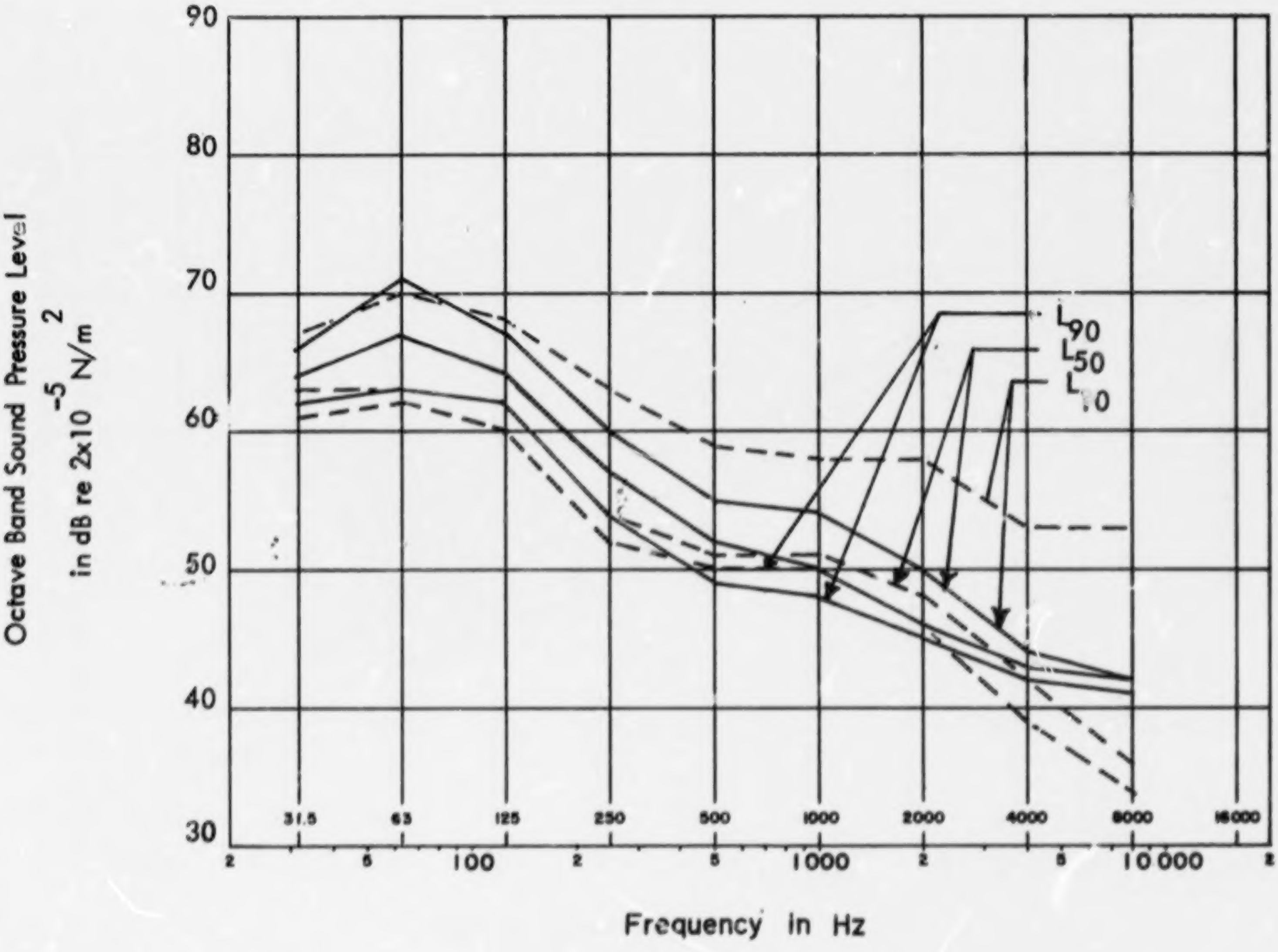


Figure 3.2.3-3. Oil Refinery Location 3

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

— — — Nighttime

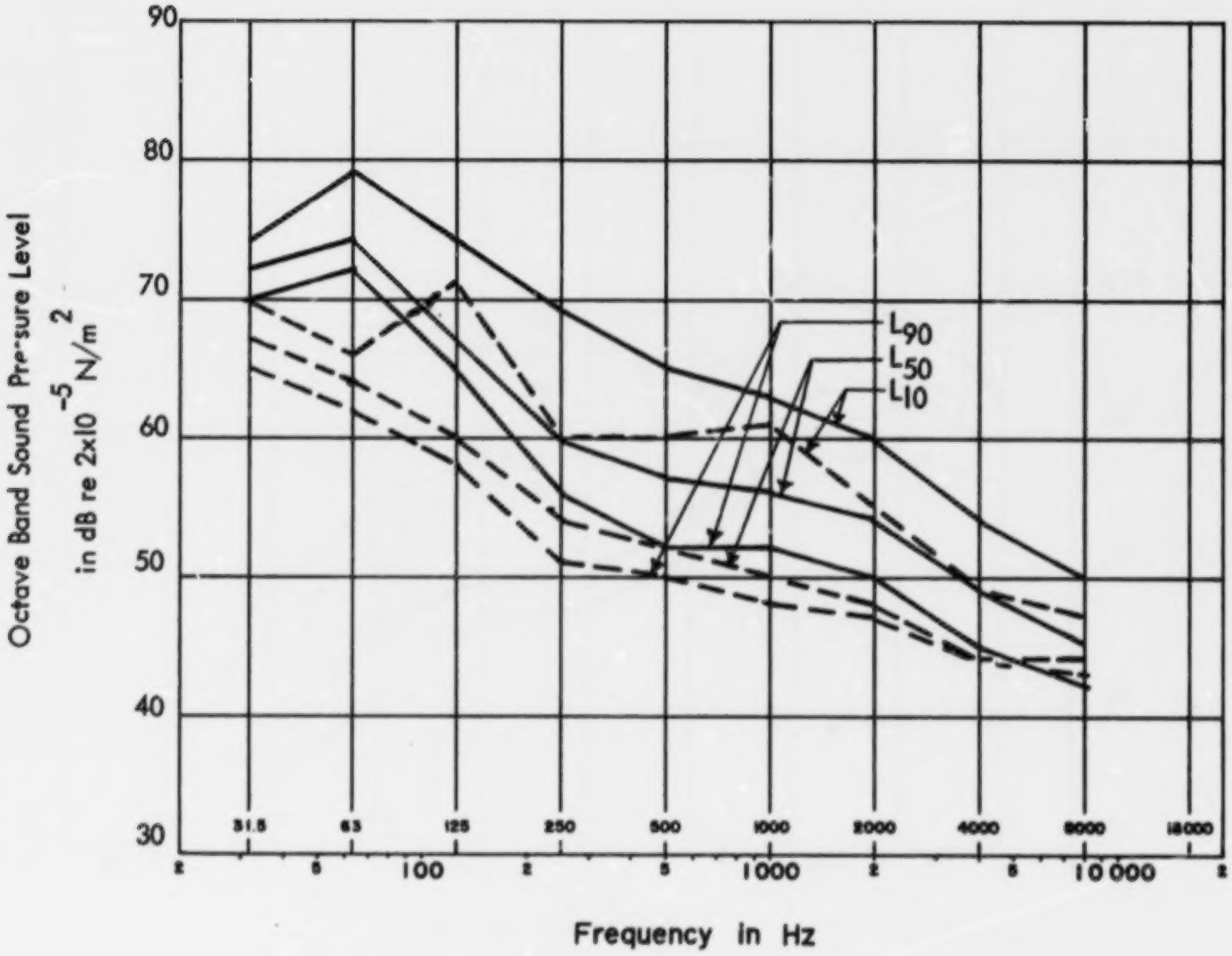


Figure 3.2.3–4. Oil Refinery Location 4.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

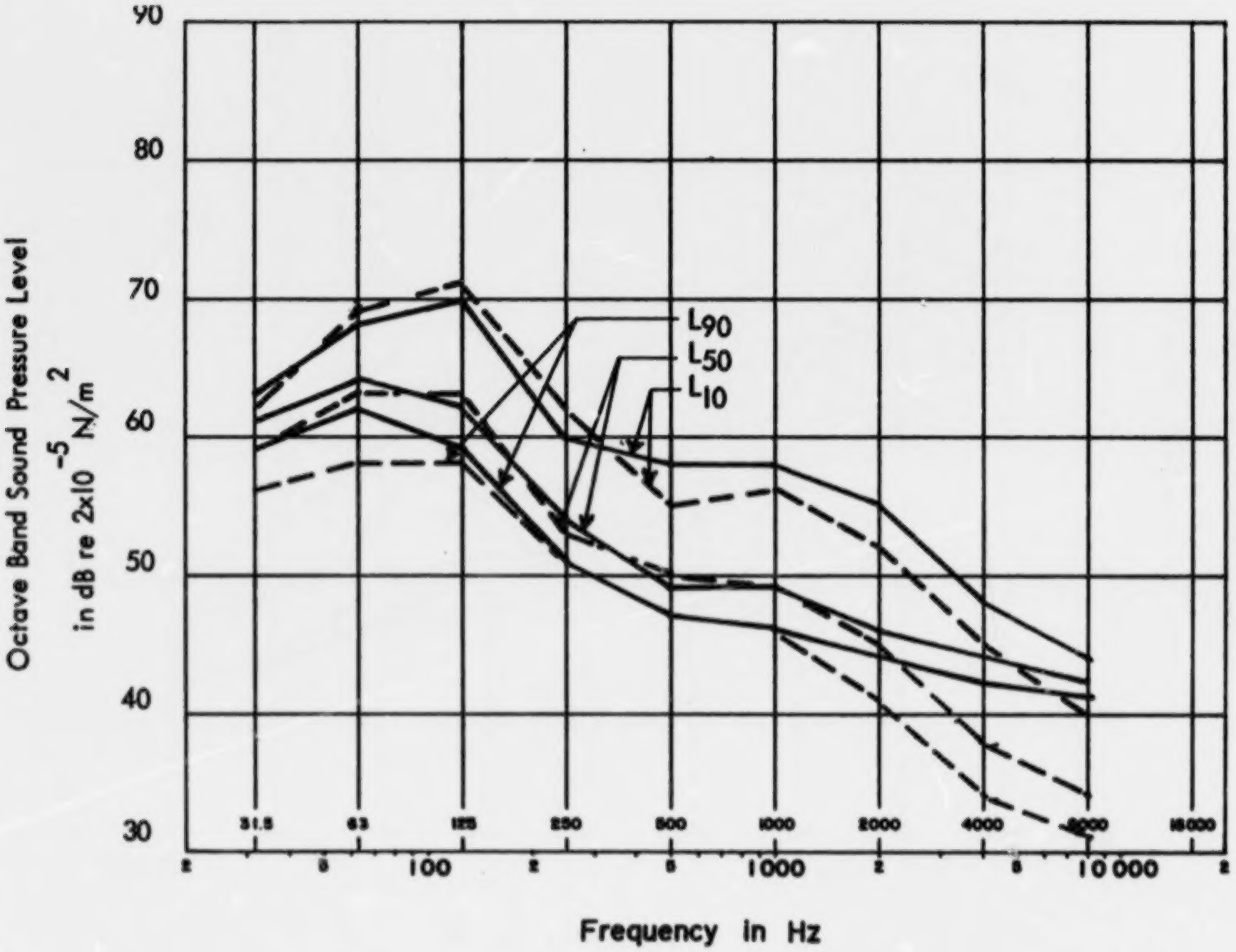


Figure 3.2.3-5. Oil Refinery Location 5.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

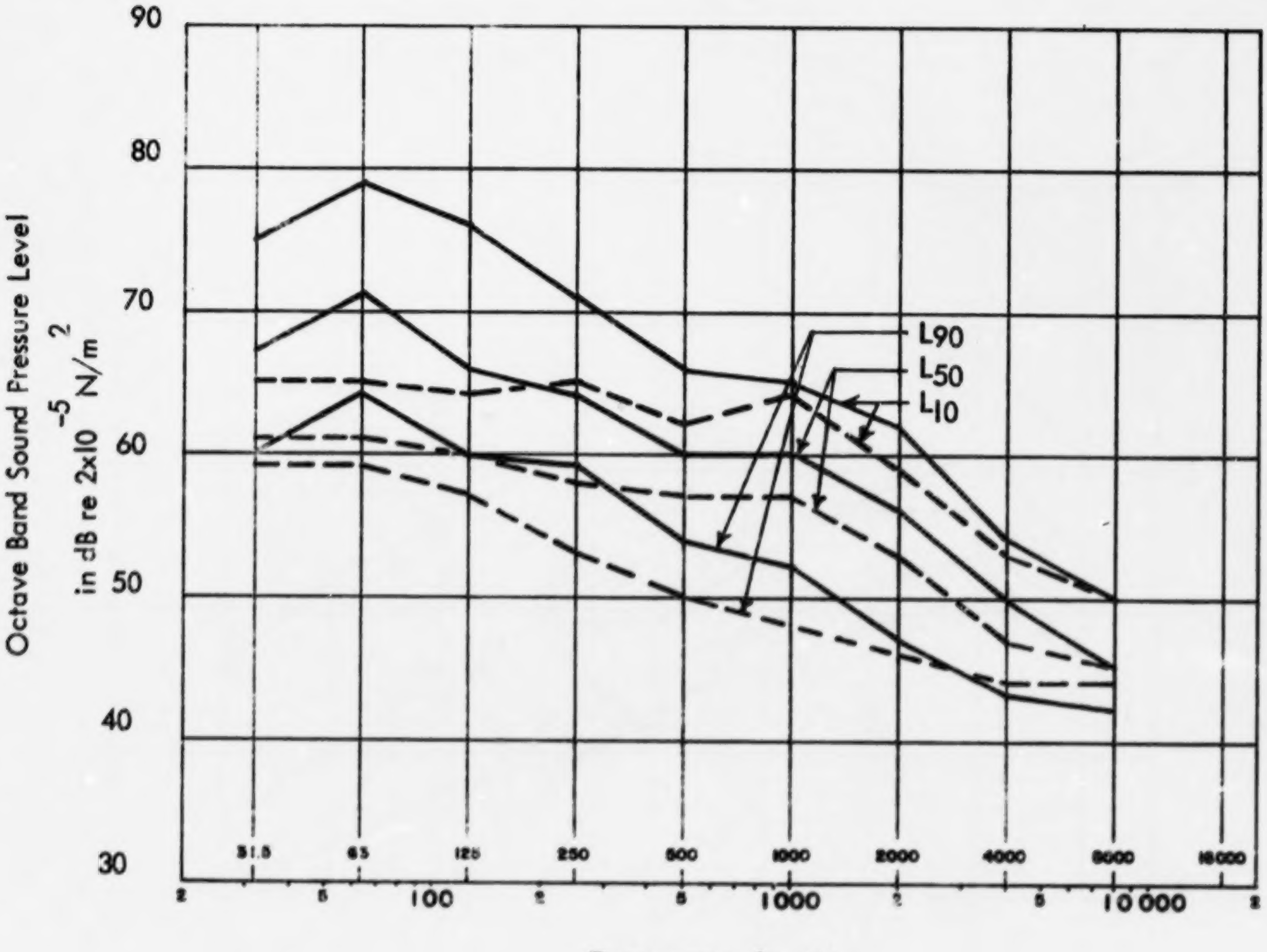


Figure 3.2.3-6. Oil Refinery Location 6.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

NOT REPRODUCIBLE

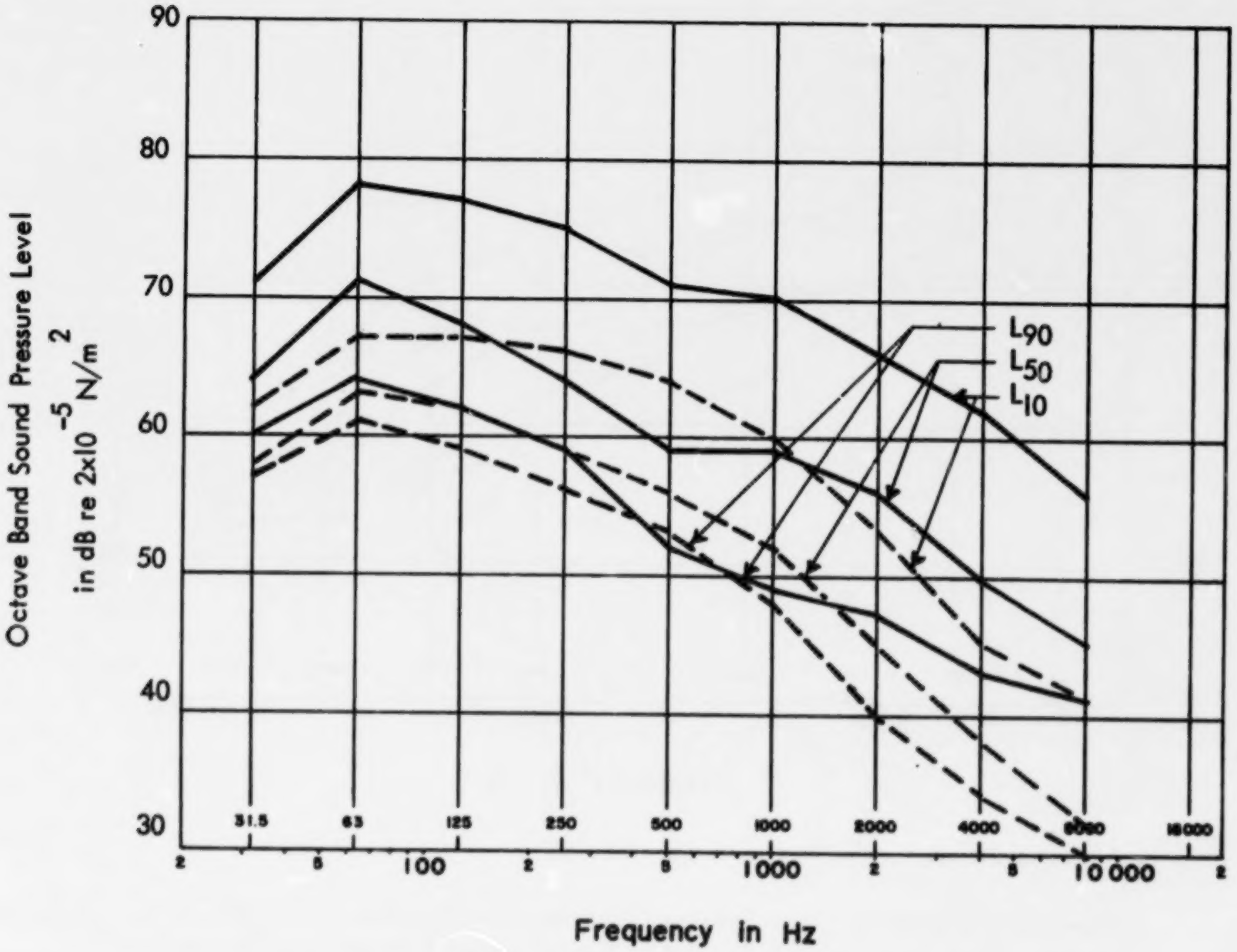


Figure 3.2.3-7. Oil Refinery Location 7.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

—— Daytime

--- Nighttime

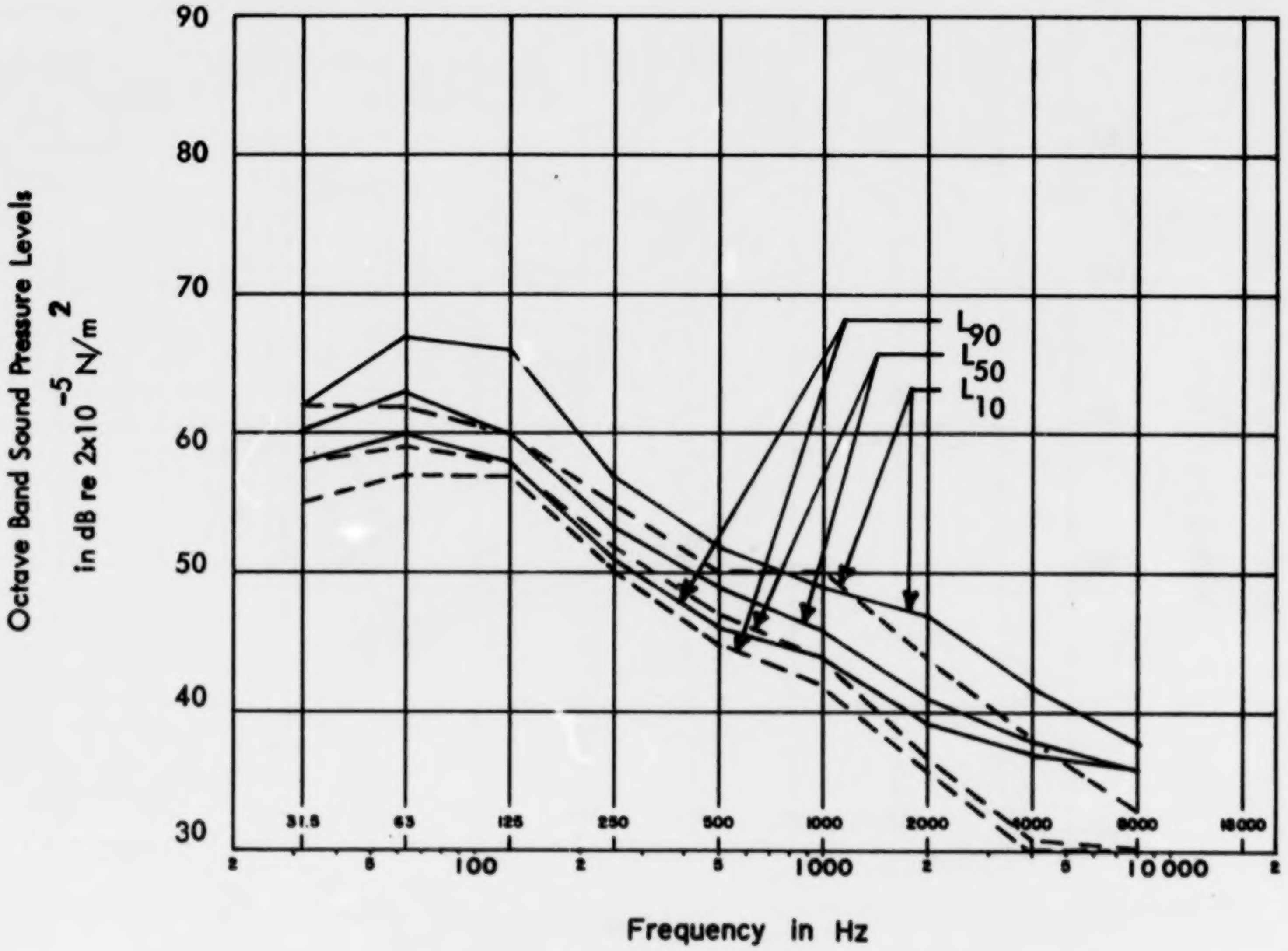


Figure 3.2.3-8. Oil Refinery Location 8

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – – Nighttime

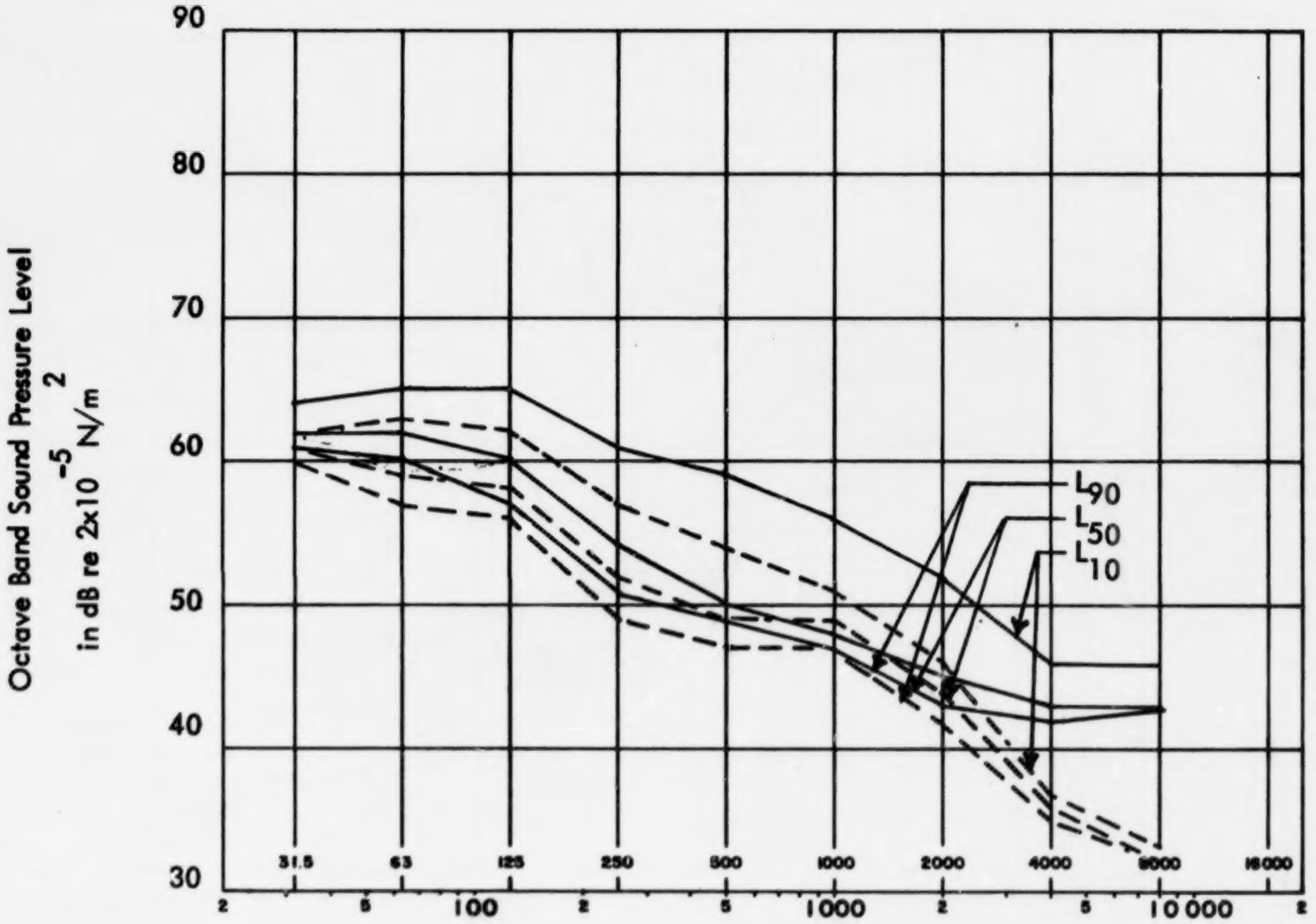


Figure 3.2.3-9. Oil Refinery Location 9

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – – Nighttime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
60
61
62 ************************
63 *************
64 ********
65 ***
66 **
67
68
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
60
61 *******
62 **************
63 ******
64 ***********
65 *****
66 ***
67 ****
68
69
70
```

Number of Occurrences
Nighttime

Figure 3.2.3-10. Oil Refinery Location 1.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51
52
53 ******
54 ******
55 **
56 *****
57 ***
58 *****
59 ******
60
61 **
62 ****
63 *********
64 **
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40 **
41 *
42
43
44 *
45
46 **
47
48 ****
49 *********
50 ********
51 **
52 ***
53 **
54 ****
55 ***
56
57 *
58
59 ****
60 *
61 *
62 **
63
64
65
```

Number of Occurrences
Nighttime

Figure 3.2.3-II. Oil Refinery Location 2.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
50
51 *
52 **
53 *******
54 **************
55 **********
56 ****
57 *****
58 *
59 **
60 *
61 *
62 *
63 *
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
45 ********************
46 ******************
47 *******
48 ***
49 *
50
51 *
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.2.3-12. Oil Refinery Location 3.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^{2}

```
55
56
57 *
58 ***
59 ***
60 *******
61 ****
62 *******
63 *****
64 ****
65 ***
66 ***
67 **
68 **
69 ****
70 **
71
72
73
74
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^{2}

```
45
46
47
48
49 **
50 **********************
51 ******
52 ***
53 ***
54
55 ***
56 **
57 ***
58 *
59 ***
60 **
61
62
63
64
65
```

Number of Occurrences
Nighttime

Figure 3.2.3-13. Oil Refinery Location 4.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51
52
53 **
54 *********
55 ***************
56 ********
57 ****
58 ***
59 *
60 **
61 *
62
63
64 *
65 *
66 **
67
68 *
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45 *******
46 ****
47 *************
48 ******
49 ************
50 **
51 *
52 ***
53 *
54 *
55
```

Number of Occurrences
Nighttime

Figure 3.2.3-14. Oil Refinery. Location 5.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55 *
56 **
57
58 **
59
60 *
61 **
62 *****
63 **
64 *****
65 ********
66 ***
67 ********
68 *
69 ****
70
71 **
72
73 *
74 ***
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46
47 ****
48 *****
49 ******
50 **
51 ****
52 ****
53 ******
54
55 **
56 **
57 ****
58 **
59 **
60 *
61
62 **
63 *
64
65 **
66 *
67
68
69
70
```

Number of Occurrences
Nighttime

Figure 3.2.3-15. Oil Refinery Location 6.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-weighted Noise Level in dB re 2x10^{-5} N/m^2

```
50
51
52
53 **
54
55 **
56 ***
57 ***
58 **
59 *
60 **
61 ***
62 *****
63 *****
64 ******
65
66 ***
67
68
69 ****
70
71
72
73 ***
74 *
75 *
76 *
77 *
78
79 *
80 *
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40
41
42
43
44 ********
45 *******************
46 *********
47 **
48 *******
49 **
50 ***
51
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.2.3-16. Oil Refinery Location 7.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
45
46
47 **********
48 ******************
49 **********
50 *
51 *
52 ****
53 **
54
55 ***
56
57 *
58
59
60
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
40
41
42
43
44 ***
45 *******************
46 ***************
47 *************
48
49
50
```

Number of Occurrences
Nighttime

Figure 3.2.3-17. Oil Refinery Location 8.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51 *************
52 *********
53 ***********
54 **
55 ****
56 **
57 *****
58
59
60 *
61 ***
62
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46
47 *******
48 ***************
49 ****
50 ********
51 ***
52 ***
53 ***
54
55 *
56 *
57
58 *
59 **
60
61
62
63 **
64
65
```

Number of Occurrences
Nighttime

Figure 3.2.3-18. Oil Refinery Location 9.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

Table 3.2.3-1 - Intrusive (L_{10}) Noise Level (A-Weighted) Observed at Oil Refinery Community Locations During Day, Evening, and Nighttime Sampling Periods

	Noise Level dB(A)		
Location	Day	Evening	Night
1	72	66	66
	64	74	65
	73	72	
		54	
2	60	55	59
	61	58	58
	62	63	
		61	
3	50	55	47
	59	56	57
	59	64	
		61	
4	66	57	58
	63	52	64
	68	55	
		60	
5	58	61	51
	62	61	55
	49	57	50
6	63	67	60
	56	65	60
	78	54	54
	70		
7	66	64	57
	74	65	48
	73		48
			53
8	56	54	50
	53	53	48
	58		50
			53
9	61	56	51
	57	69	55
	58		54
			59

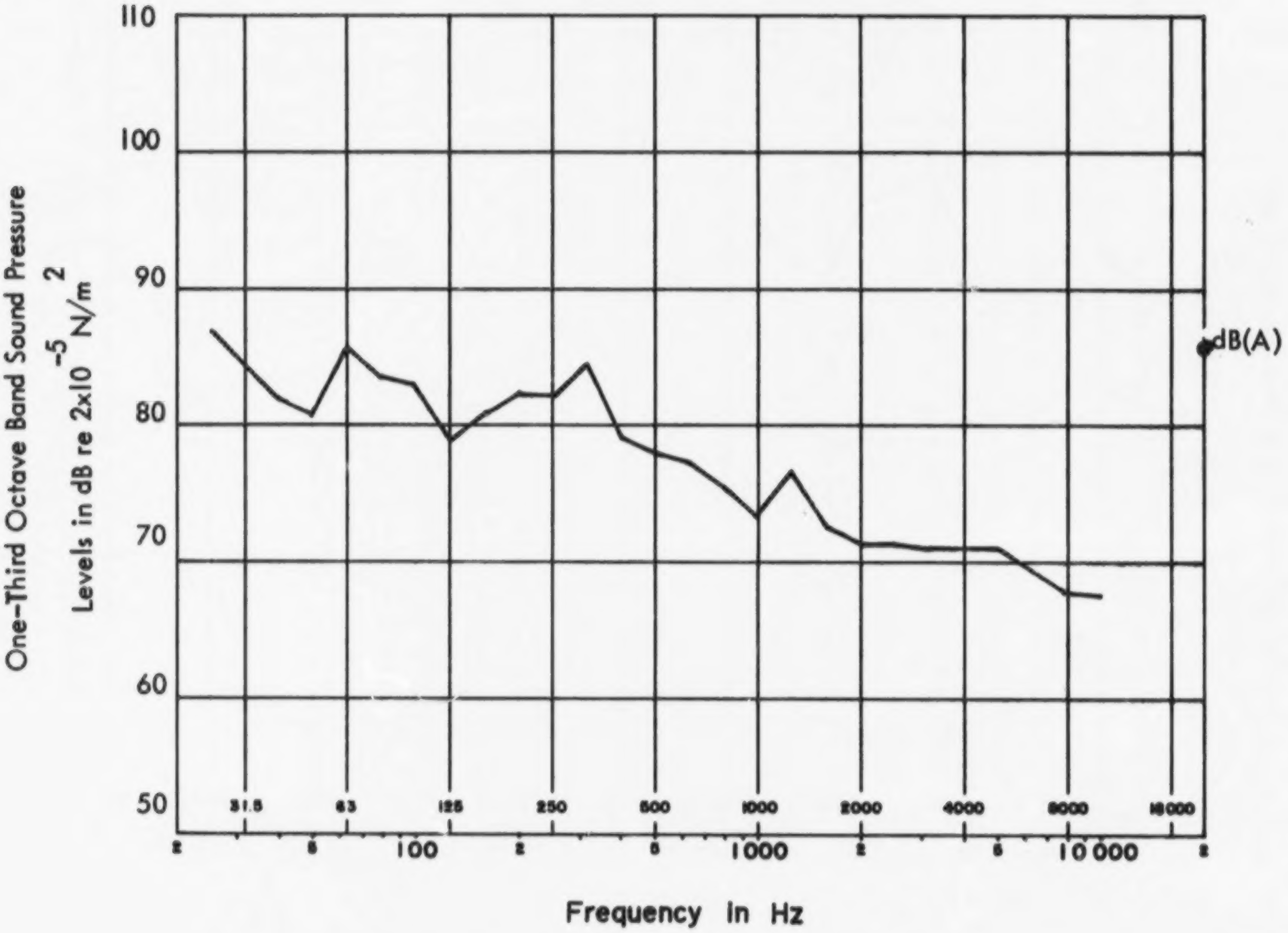


Figure 3.3.2-1. One-Third Octave Band Sound Pressure Levels Measured near Two Induced Draft Fans in a Power Plant.

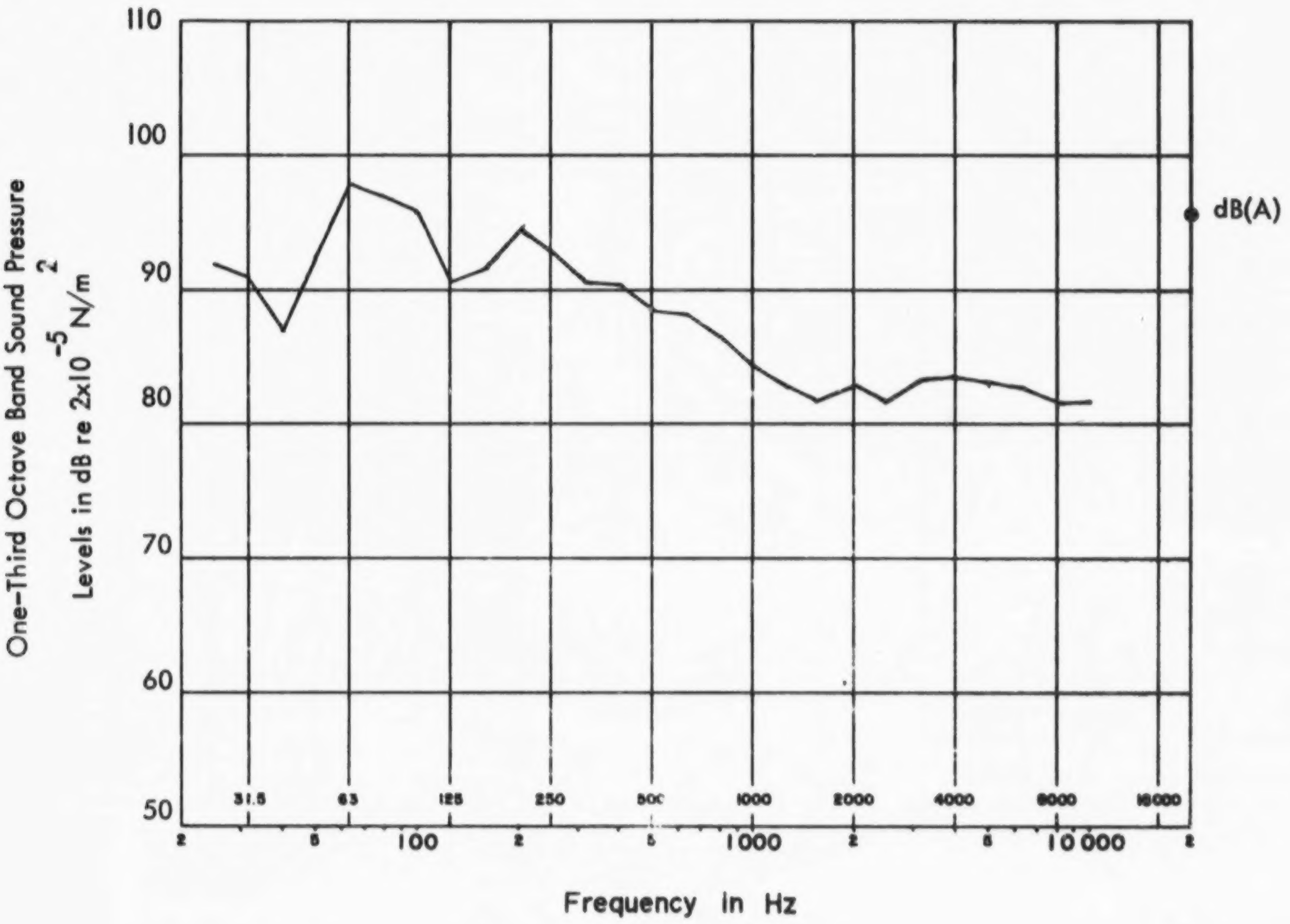


Figure 3.3.2-2. One-Third Octave Band Sound Pressure Levels Measured near a Forced Draft Fan Inlet in a Power Plant.

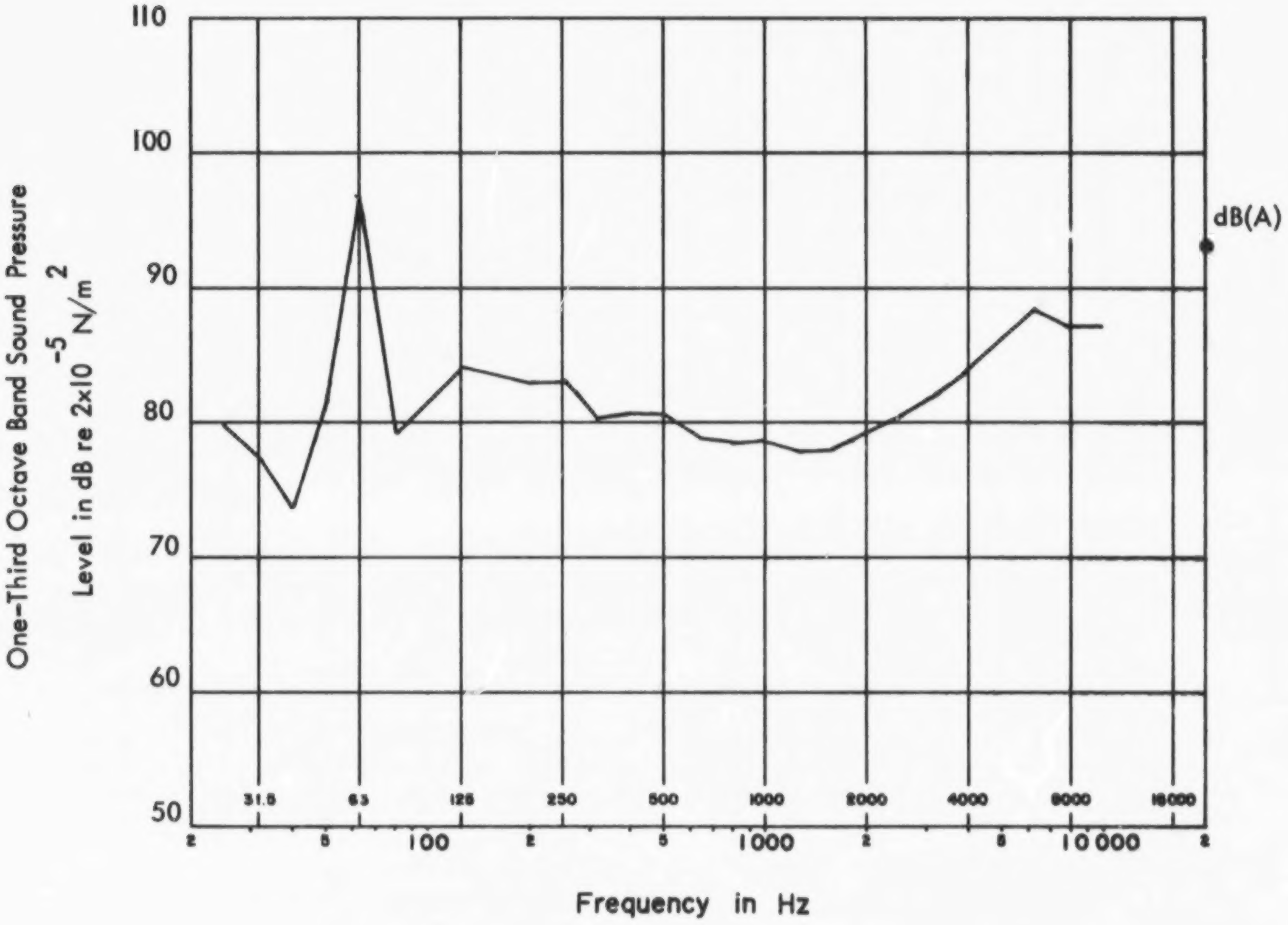


Figure 3.3.2-3. One-Third Octave Band Sound Pressure Levels Measured near a Steam Turbine Generator in a Power Plant.

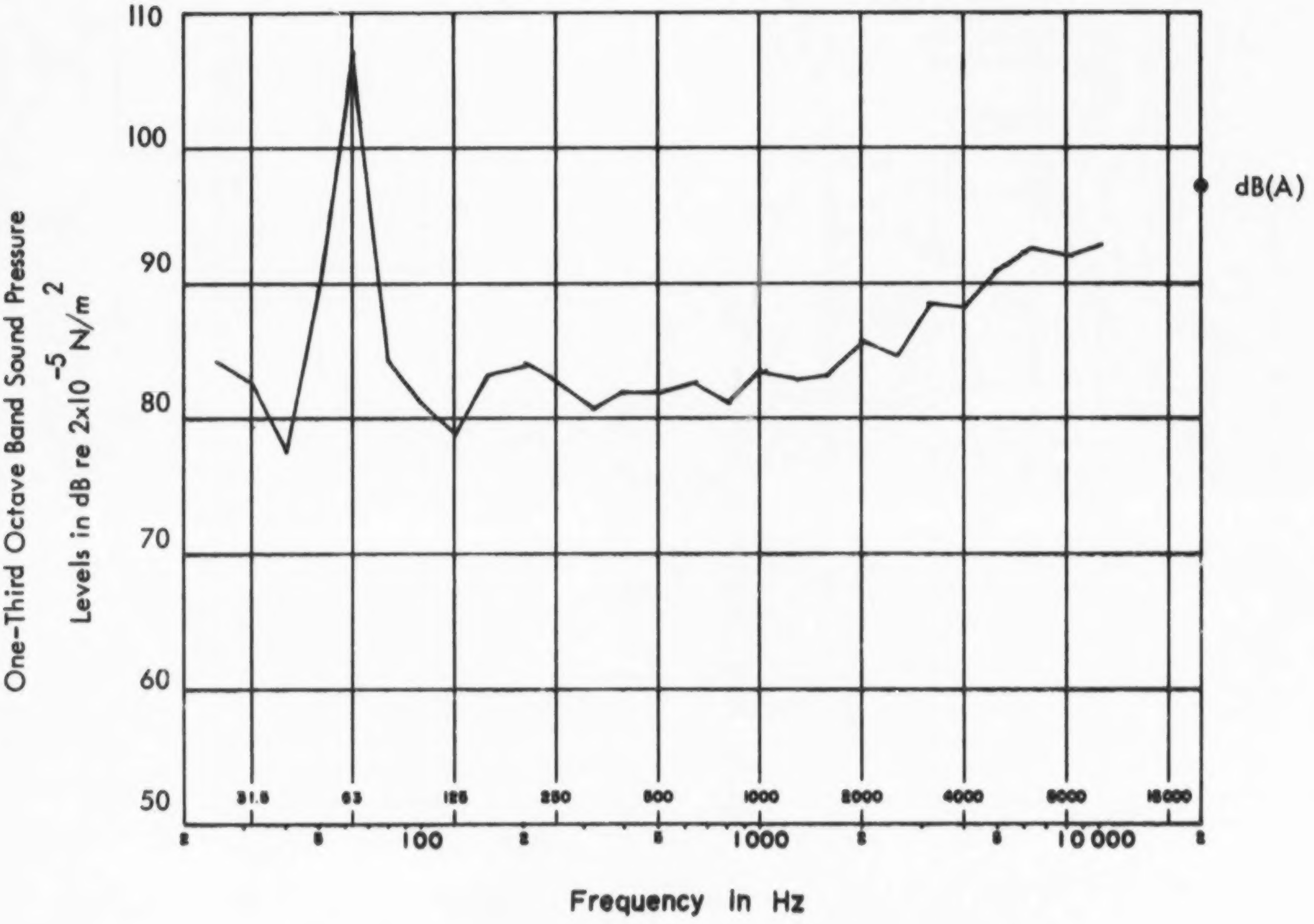
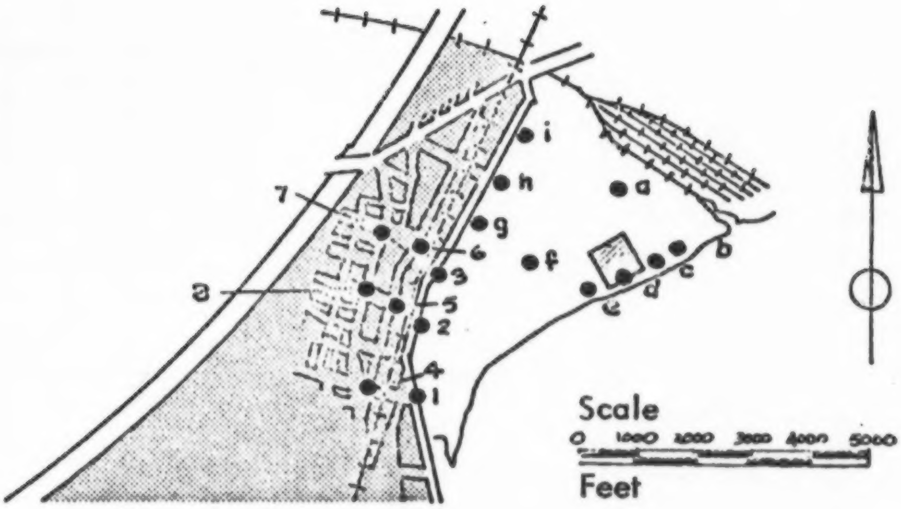


Figure 3.3.2-4. One-Third Octave Band Sound Pressure Levels Measured in the Compressor Room in a Power Plant.


7
8
i
h
a
g
6
f
3
5
2
4
1
b
c
d
e
Scale
0 1000 2000 3000 4000 5000
Feet

Community Noise Levels in dB(A)

	1	2	3	4	5	6	7	8
Weekend	48	50	50	50	52	58	57	54
Weekday	48	51	49	53	55	56	55	54
Weeknight	51	52	52	52	53	56	57	54

Plant Property Line Noise Levels in dB(A)

	a	b	c	d	e	f	g	h	i
Weekend	81	58	63	69	64	53	54	59	68
Weekday	64	59	61	72	80	61	59	57	63
Weeknight	68	63	67	70	80	61	60	61	65

Key

▨	Industrial Noise Source
░	Residential Area
+-+-+-+-+	Railroad Track
═	Highway
●	Measurement Location

Figure 3.3.3-1. Power Plant Community

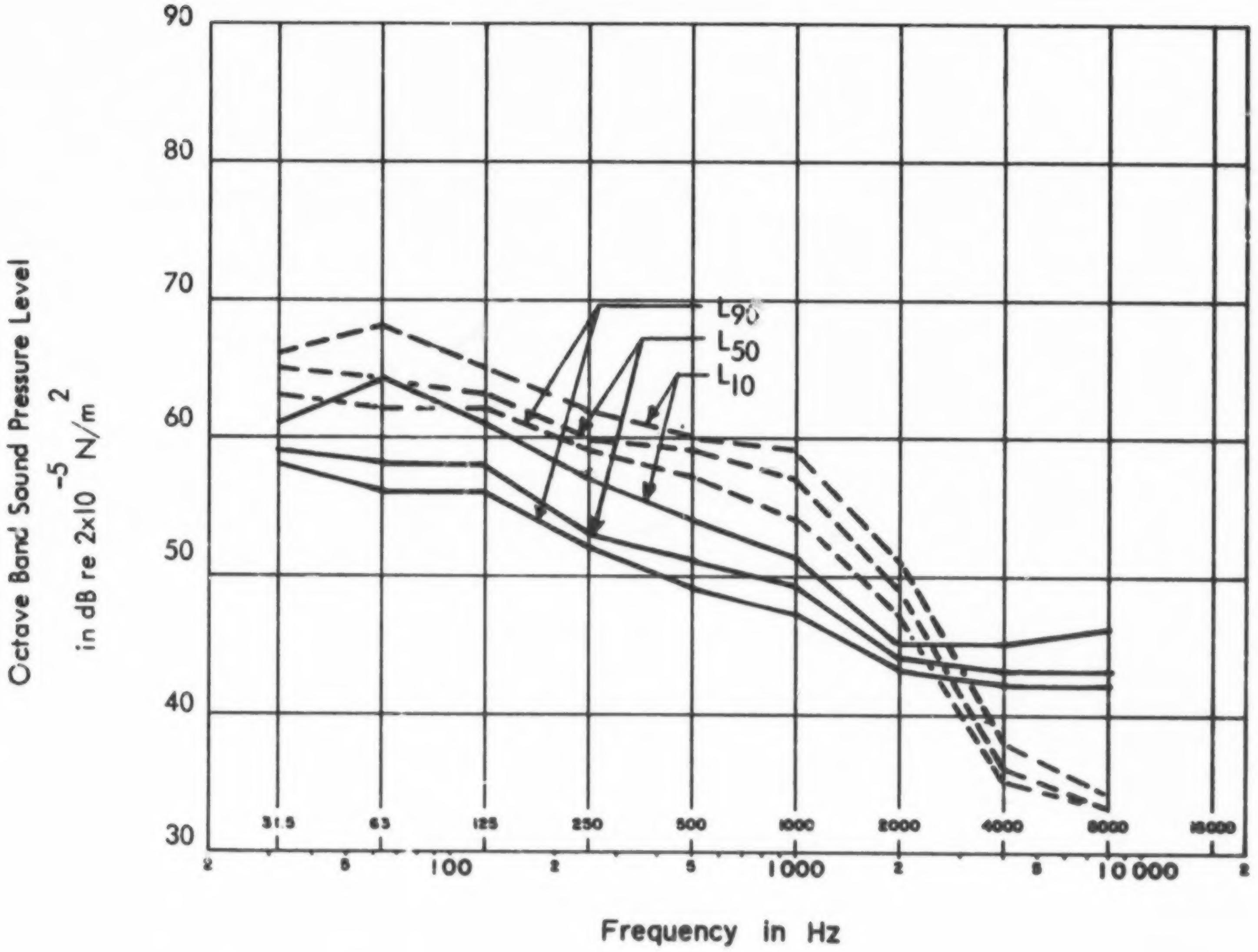


Figure 3.3.3-2. Power Plant Location I.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

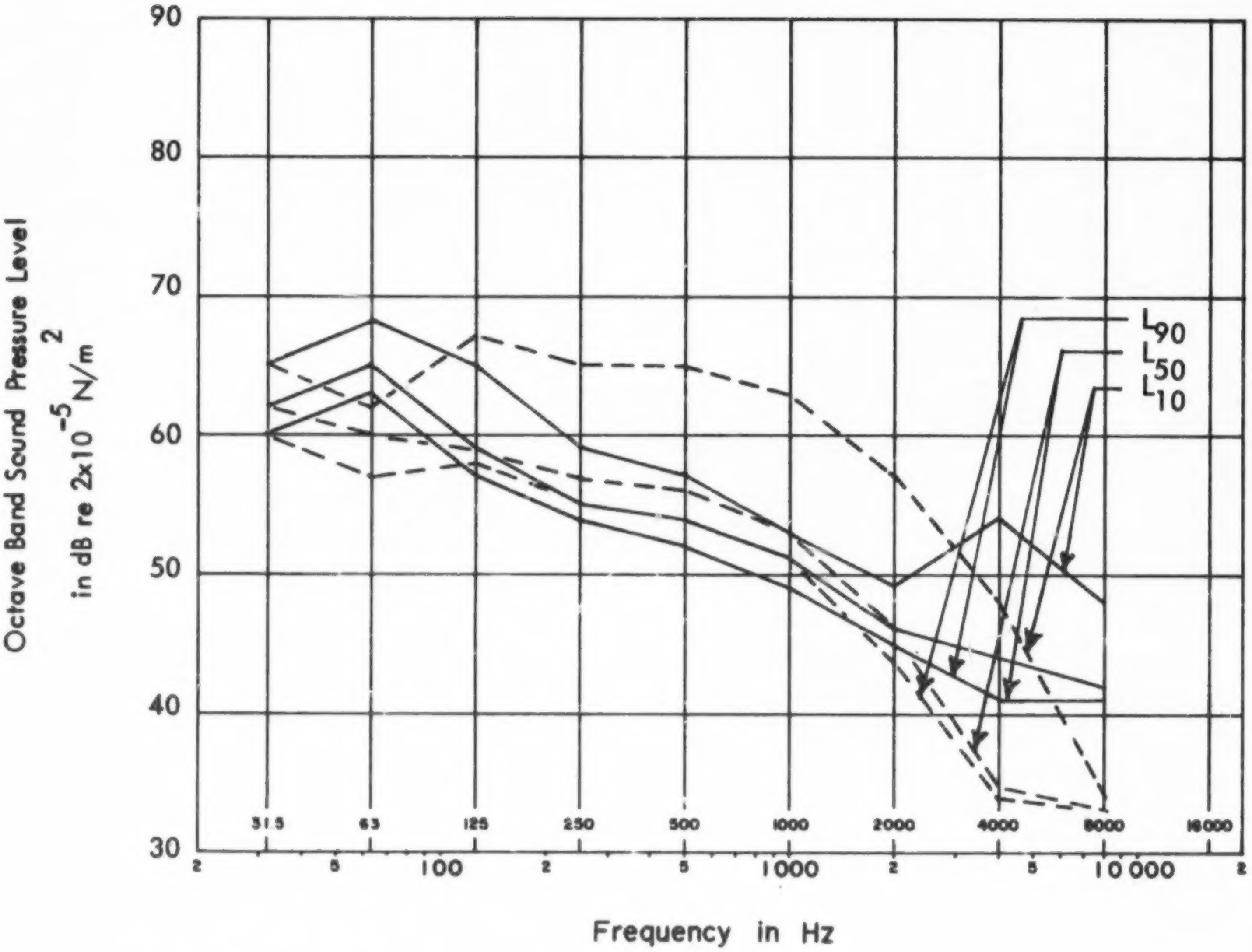


Figure 3.3.3-3. Power Plant Location 2

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

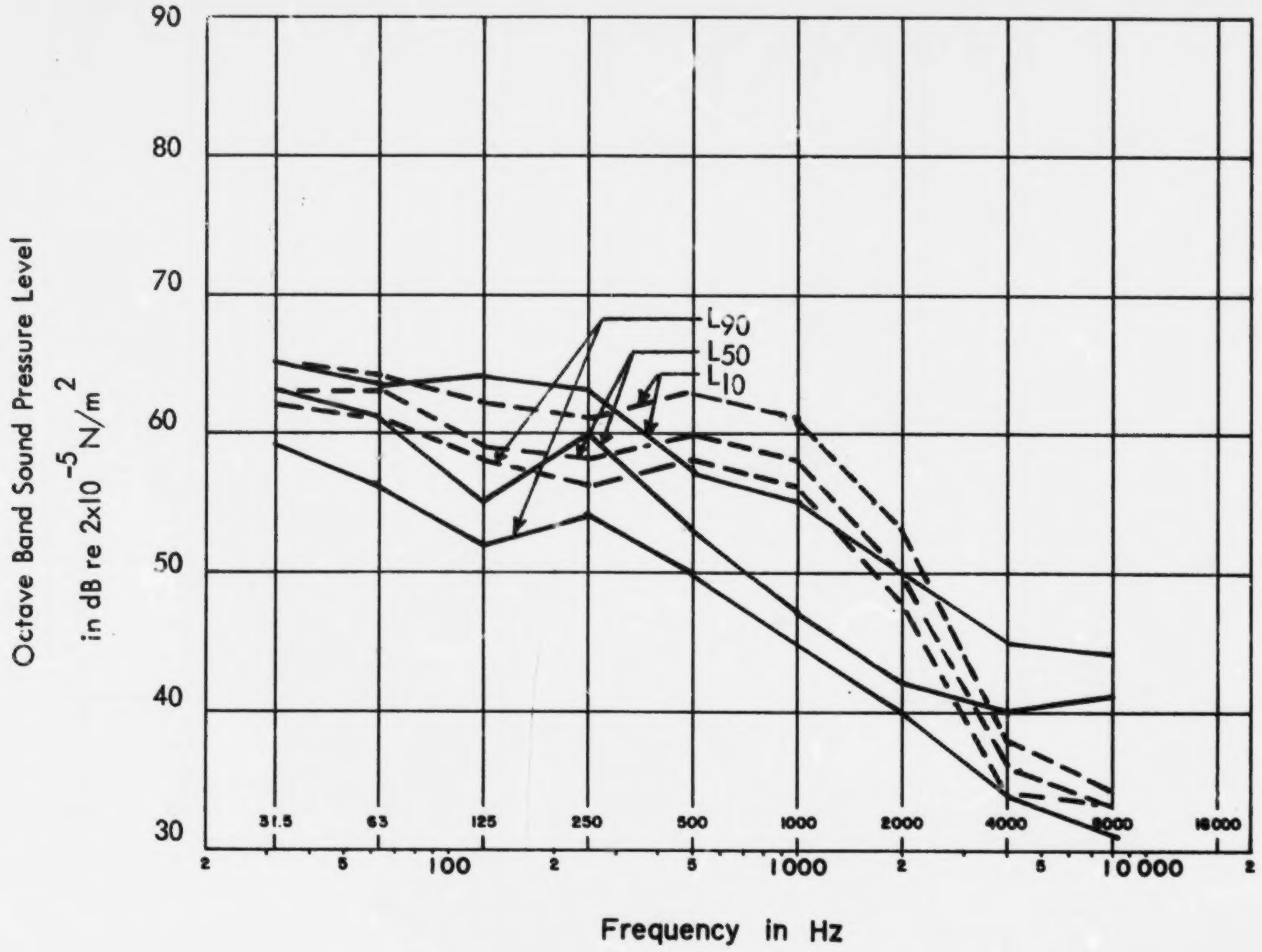


Figure 3.3.3-4. Power Plant Location 3.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10}, Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

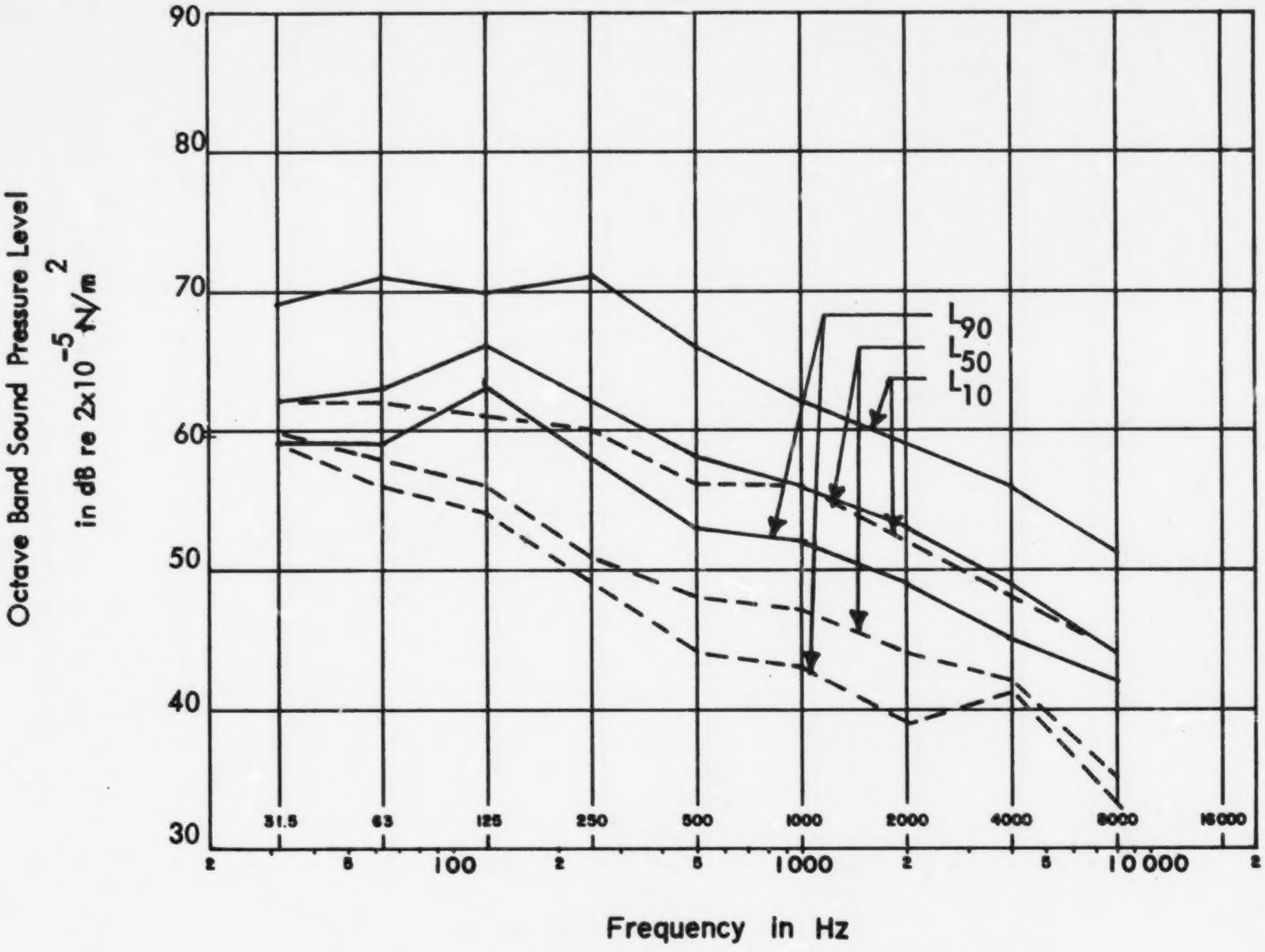


Figure 3.3.3-5. Power Plant Location 4

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

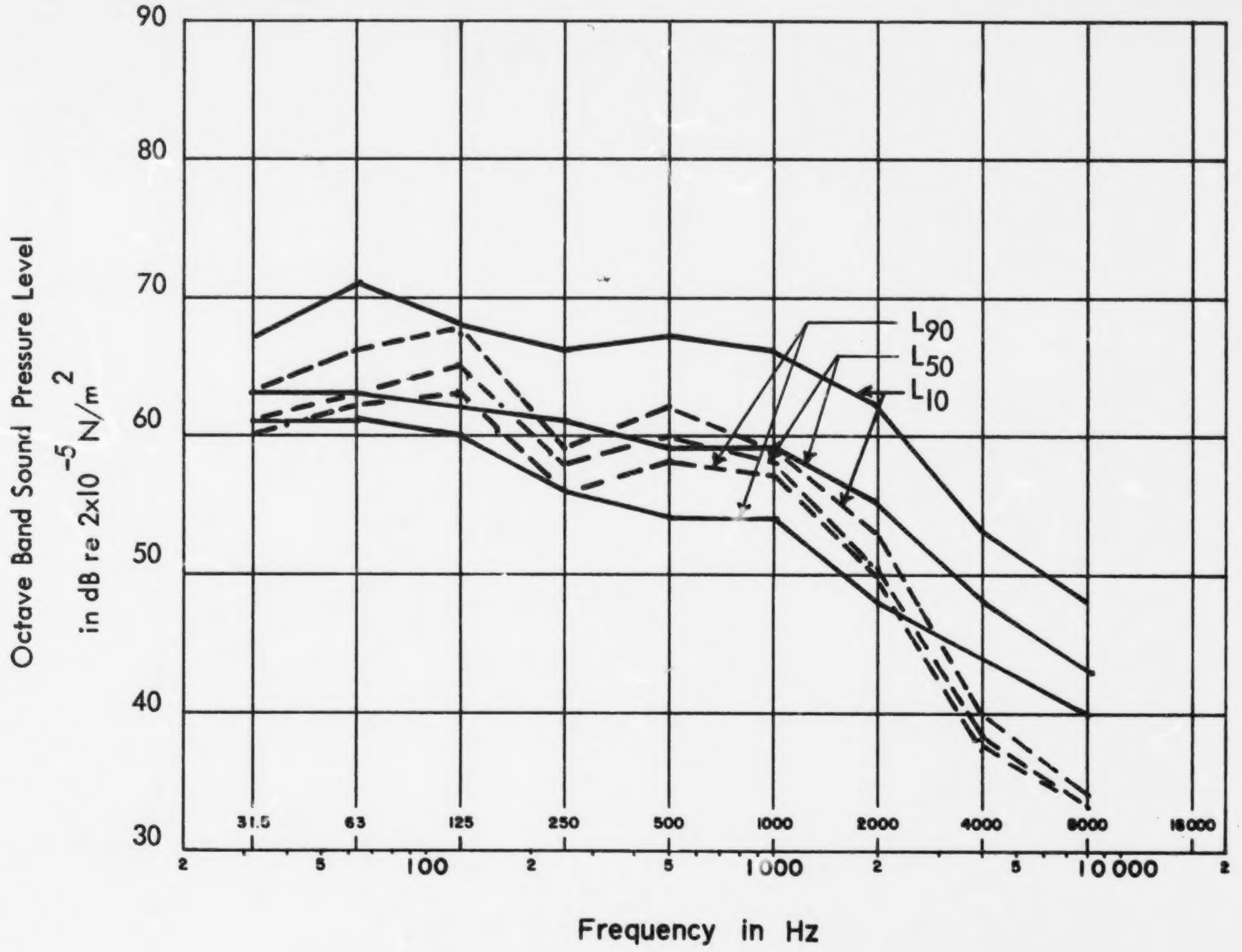


Figure 3.3.3-6. Power Plant Location 5.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

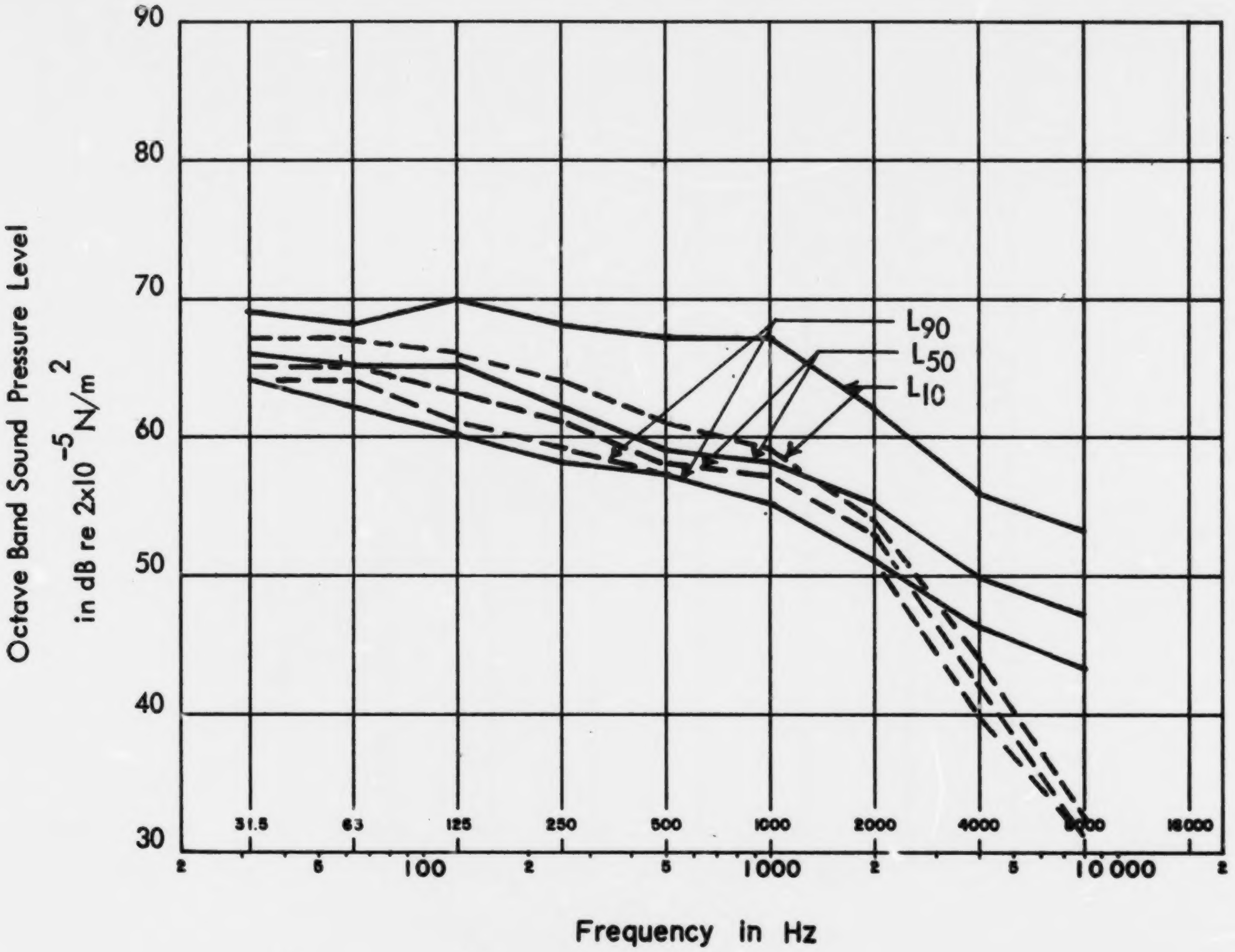


Figure 3.3.3-7. Power Plant Location 6.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

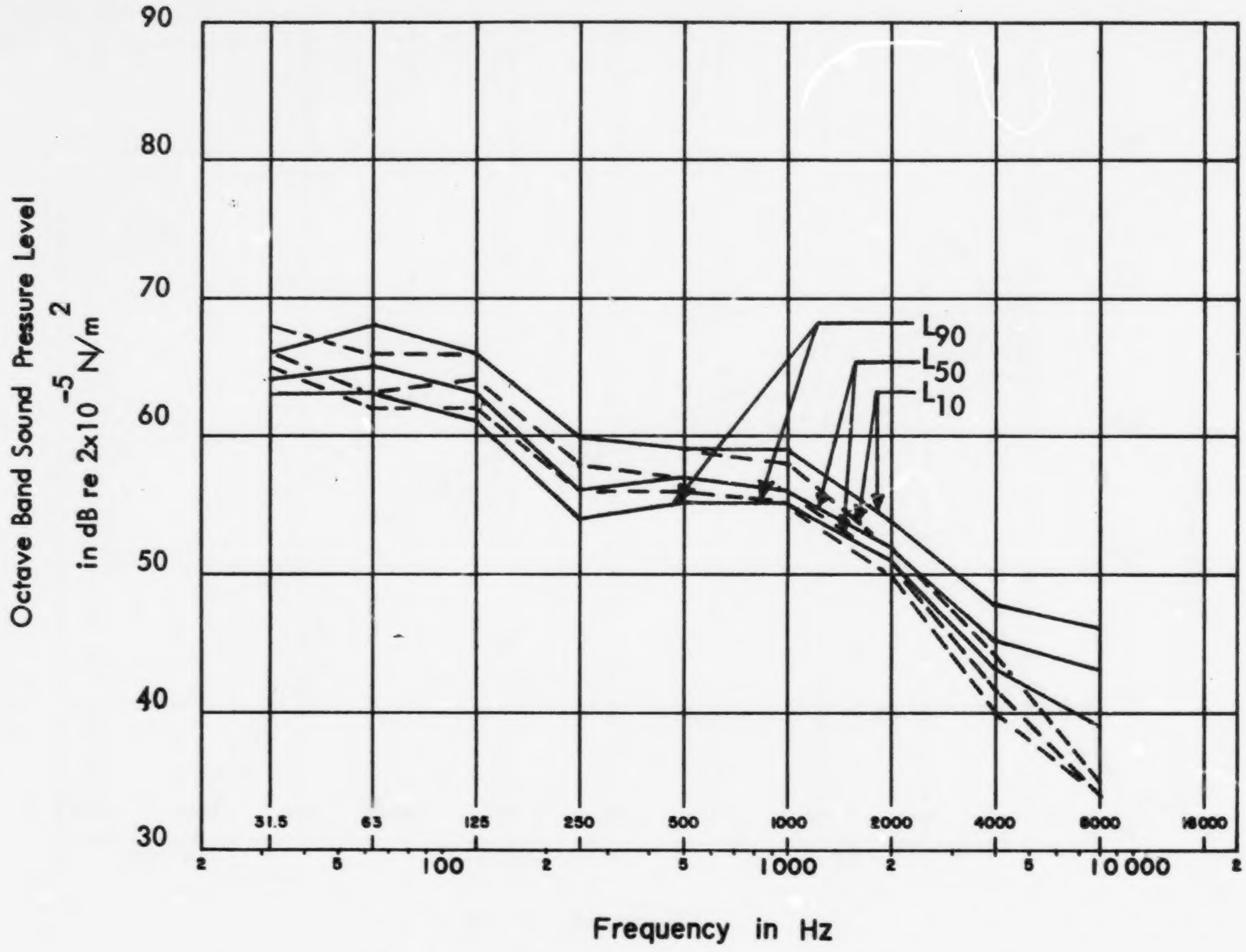


Figure 3.3.3-8. Power Plant Location 7

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – – Nighttime

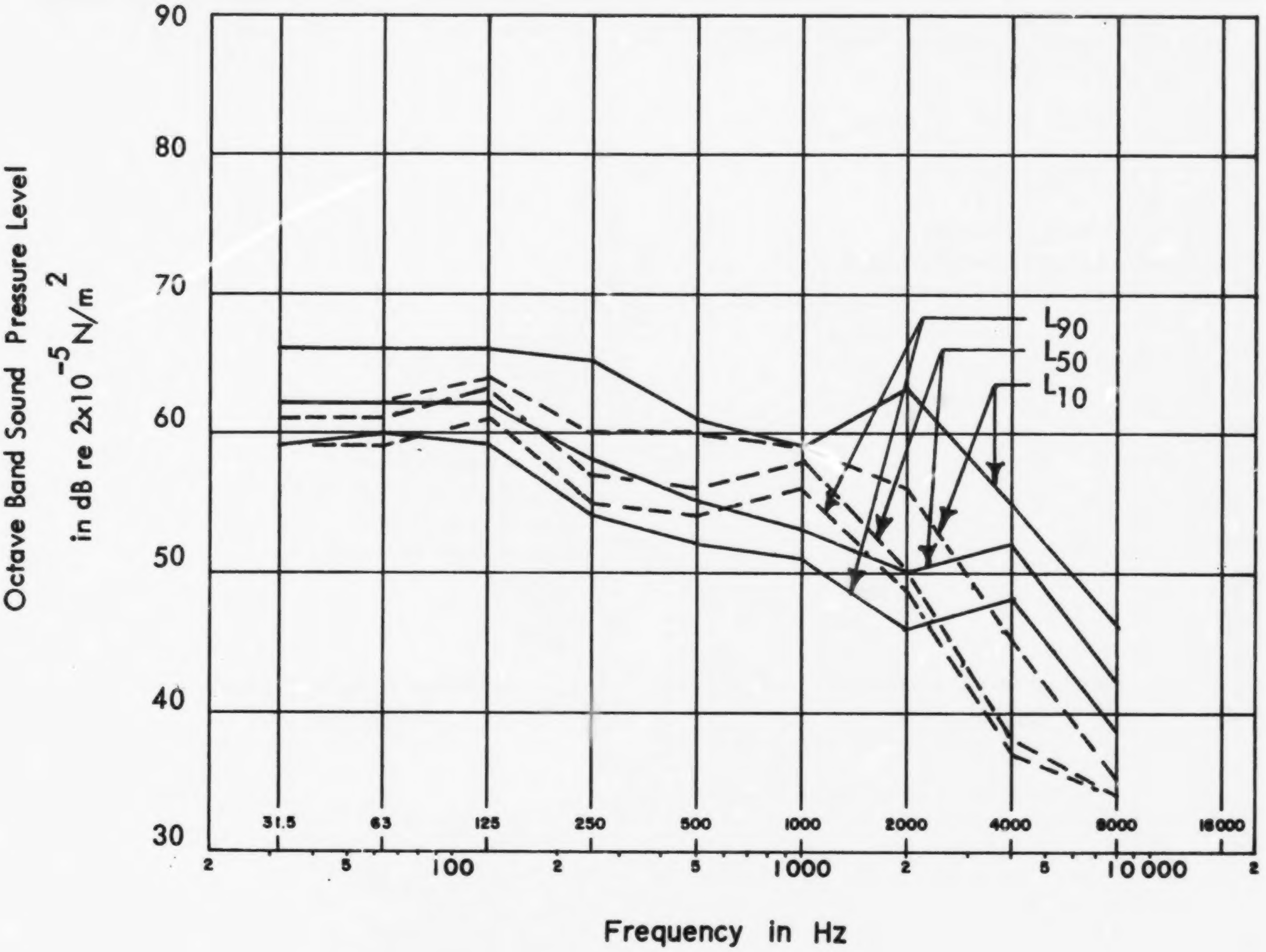


Figure 3.3.3-9. Power Plant Location 8

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

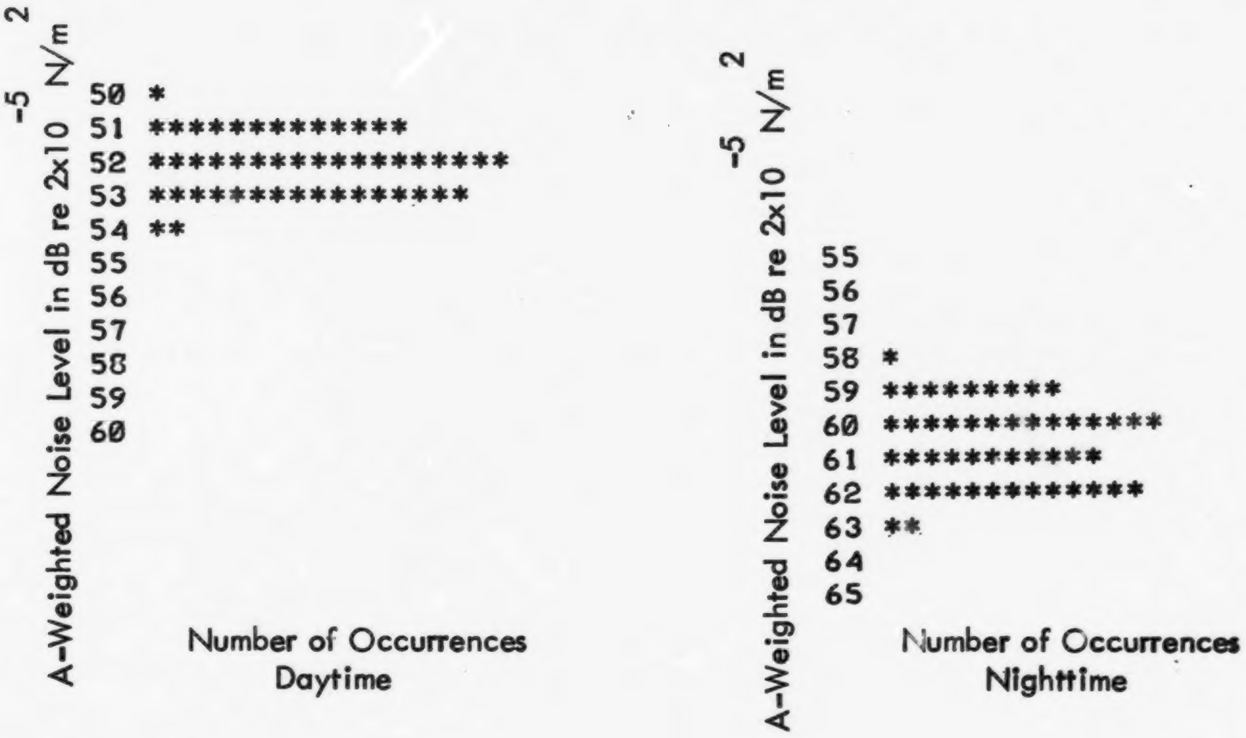


Figure 3.3.3-10. Power Plant Location 1.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
40
41
42
43
44 **
45 *
46
47
48
49 *
50
51
52 ***
53 ************
54 ***********
55 ***********
56 ****
57 *
58 **
59 *
60
61
62 *
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55
56
57
58 ****
59 *******************
60 *********
61 ******
62 **********
63 *
64 *
65
```

Number of Occurrences
Nighttime

Figure 3.3.3-11. Power Plant Location 2.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^{2}

```
45 *
46 *********
47 ****************
48 ********
49 *
50 **
51
52
53 *
54 ***
55
56 **
57 *
58
59
60 ****
61 *
62 *
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^{2}

```
55
56
57
58
59 **
60 *************
61 *************
62 ************
63 *
64 *****
65 ***
66
67
68
69
70 *
```

Number of Occurrences
Nighttime

Figure 3.3.3-12. Power Plant Location 3.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
55
56 *
57 **
58 *******
59 *
60 *****
61 ******
62 **
63 ****
64 ********
65 **
66 **
67 *
68 **
69 *
70
71 ***
72 **
73 *
74
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
55
56
57
58
59 ********
60 *************
61 ********
62 ***********
63 ******
64 **
65 **
```

Number of Occurrences
Nighttime

Figure 3.3.3-13. Power Plant Location 4.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56
57 **
58 ********
59 ***
60 *****
61 **
62 **
63 **
64 *
65 *
66 ***
67 ******
68 ********
69 ***
70 *
71 ***
72
73
74
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56
57
58
59
60 ****
61 **************
62 **********************
63 *********
64 *
65
```

Number of Occurrences
Nighttime

Figure 3.3.3-14. Power Plant Location 5.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56
57
58
59 **
60 ********
61 ***
62 ******
63 ***
64 **
65 *****
66 *
67 ******
68 ****
69 *******
70
71
72
73
74
75 *
76
77
78 *
79
80
81 *
82
83
84
85
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56
57 **
58 *******
59 ***************
60 *******************
61 *******
62
63
64
65
```

Number of Occurrences
Nighttime

Figure 3.3.3-15. Power Plant Location 6.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55
56
57
58 ***
59 ***************
60 ************
61 **************
62 ***
63
64 *
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79 **
80
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55
56
57
58 **
59 *****************
60 ********************
61 *********
62 *
63 *
64
65
```

Number of Occurrences
Nighttime

Figure 3.3.3-16. Power Plant Location 7.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55
56 **
57 ******
58 **********
59 **********
60 ******
61 ********
62 *
63
64 ****
65 **
66 *
67
68
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46
47
48 **
49 *
50
51
52
53
54
55
56
57
58 ****
59 ********
60 ************************
61 **
62 **
63 ***
64 **
65 **
```

Number of Occurrences
Nighttime

Figure 3.3.3-17. Power Plant Location 8.

Noise Level (A-Weighted) Histogram 50 Samples Four Secord Integration.

Table 3.3.3-1 - Intrusive (L_{10}) Noise Level (A-Weighted) Observed at Power Plant Community Locations During Day, Evening, and Nighttime Sampling Periods

	Noise Level dB(A)		
Location	Day	Evening	Night
1	52	53	60
	51	59	62
	54		51
			53
2	56	58	66
	57	49	62
	56		54
	60		57
3	59	58	58
	55	52	64
	60		51
	58		56
4	68	60	58
	64		64
	57		53
	63		63
			64
5	66		58
	69		63
	77		61
	74		53
			59
			62
6	70		58
	59		61
	56		68
	65		59
			63
			70
7	62		58
	62		61
	58		61
	62		60
			60
			60
8	62		58
	63		63
	65		60
	66		58
			58
			63

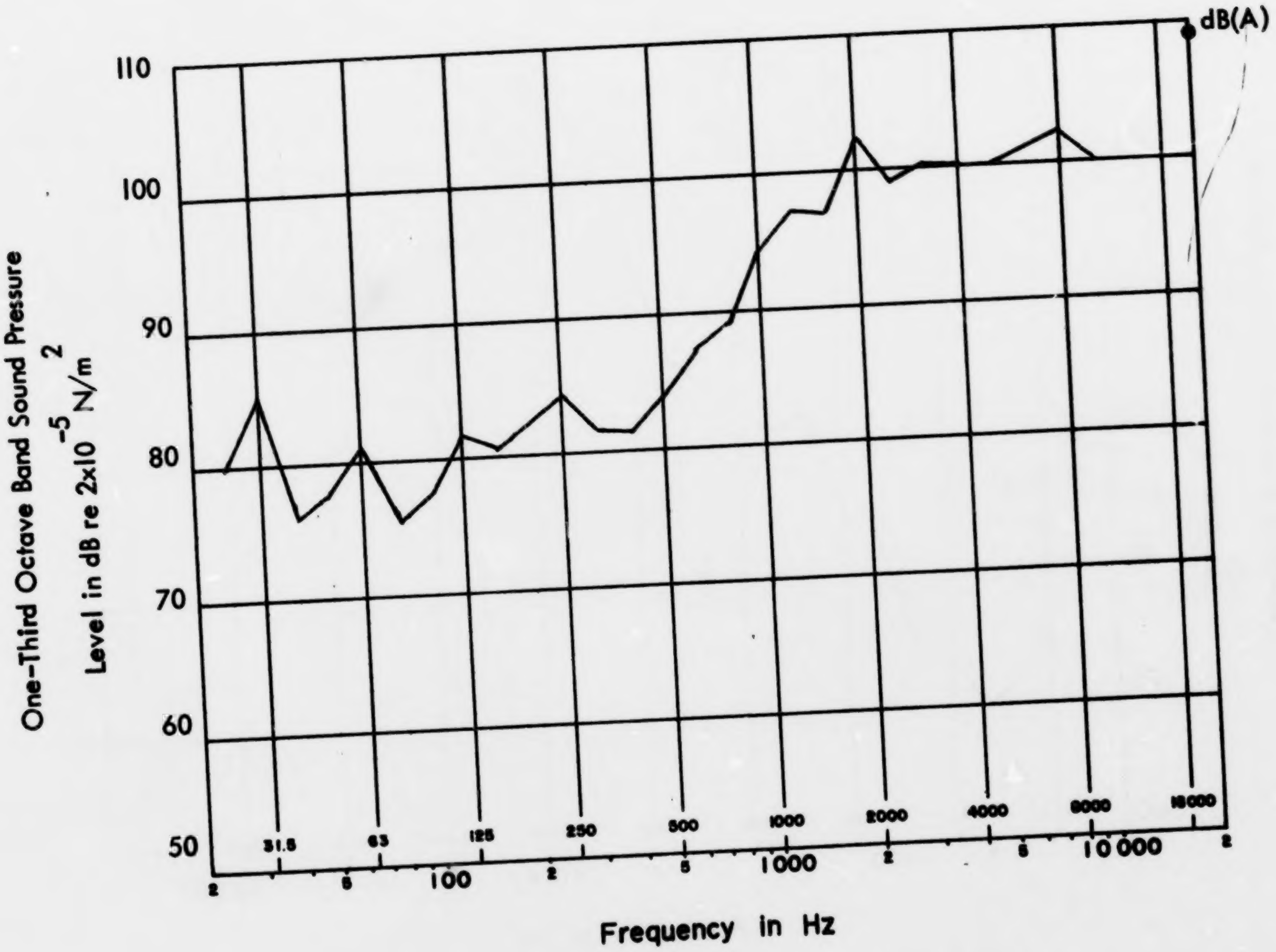


Figure 3.4.2-1. One-Third Octave Band Sound Pressure Levels Measured near the Rough Grinding Operation in an Automobile Assembly Plant.

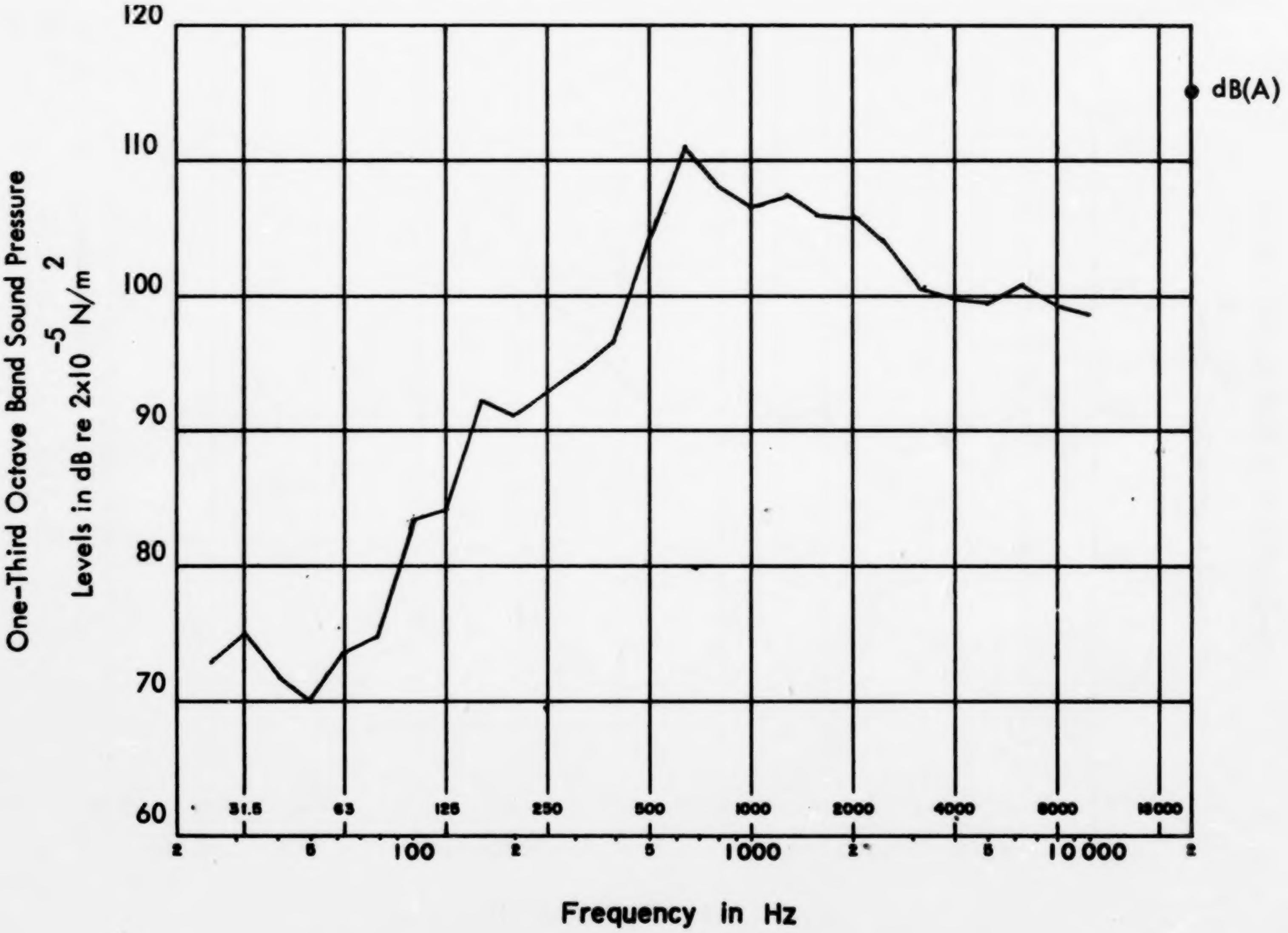


Figure 3.4.2-2. One-Third Octave Band Sound Pressure Levels Measured in the Weld Destruct (Chipping Operation) Room in an Automobile Assembly Plant.

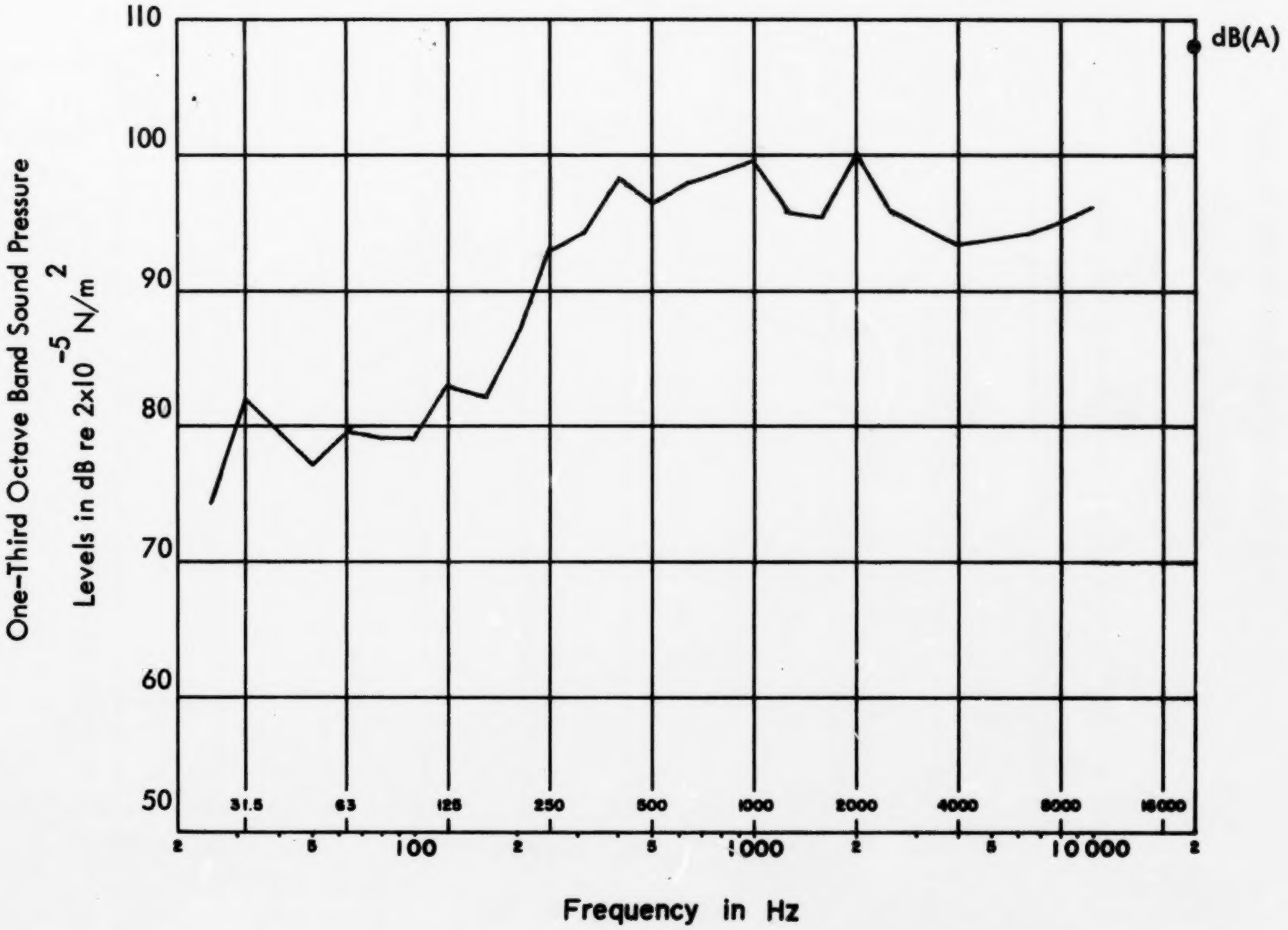


Figure 3.4.2-3. One-Third Octave Band Sound Pressure Levels Measured near the Piercing and Hole Cutting Operation in an Automobile Assembly Plant.

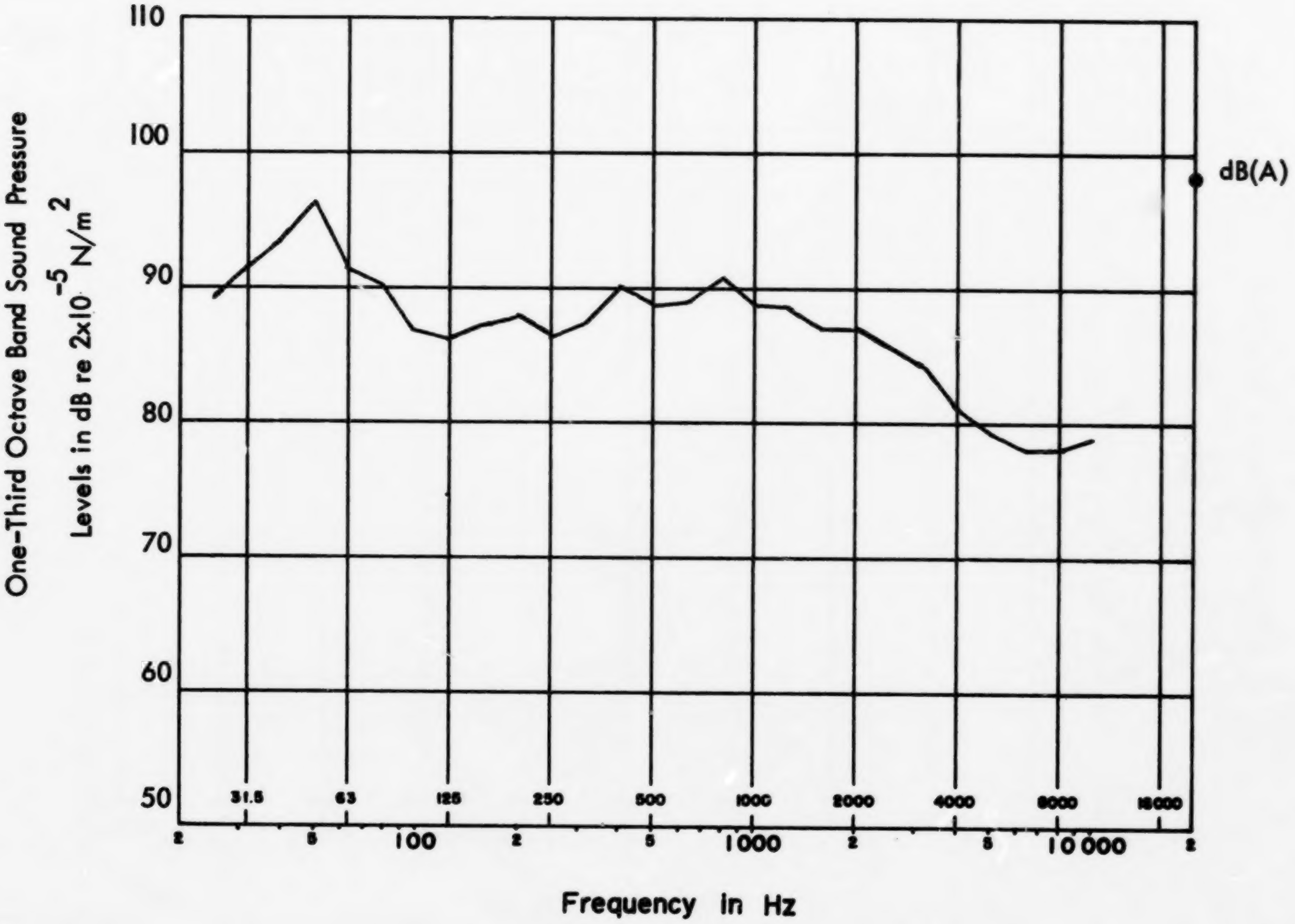


Figure 3.4.2-4. One-Third Octave Band Sound Pressure Levels Measured near a Forced Draft Air Blower in an Automobile Assembly Plant.

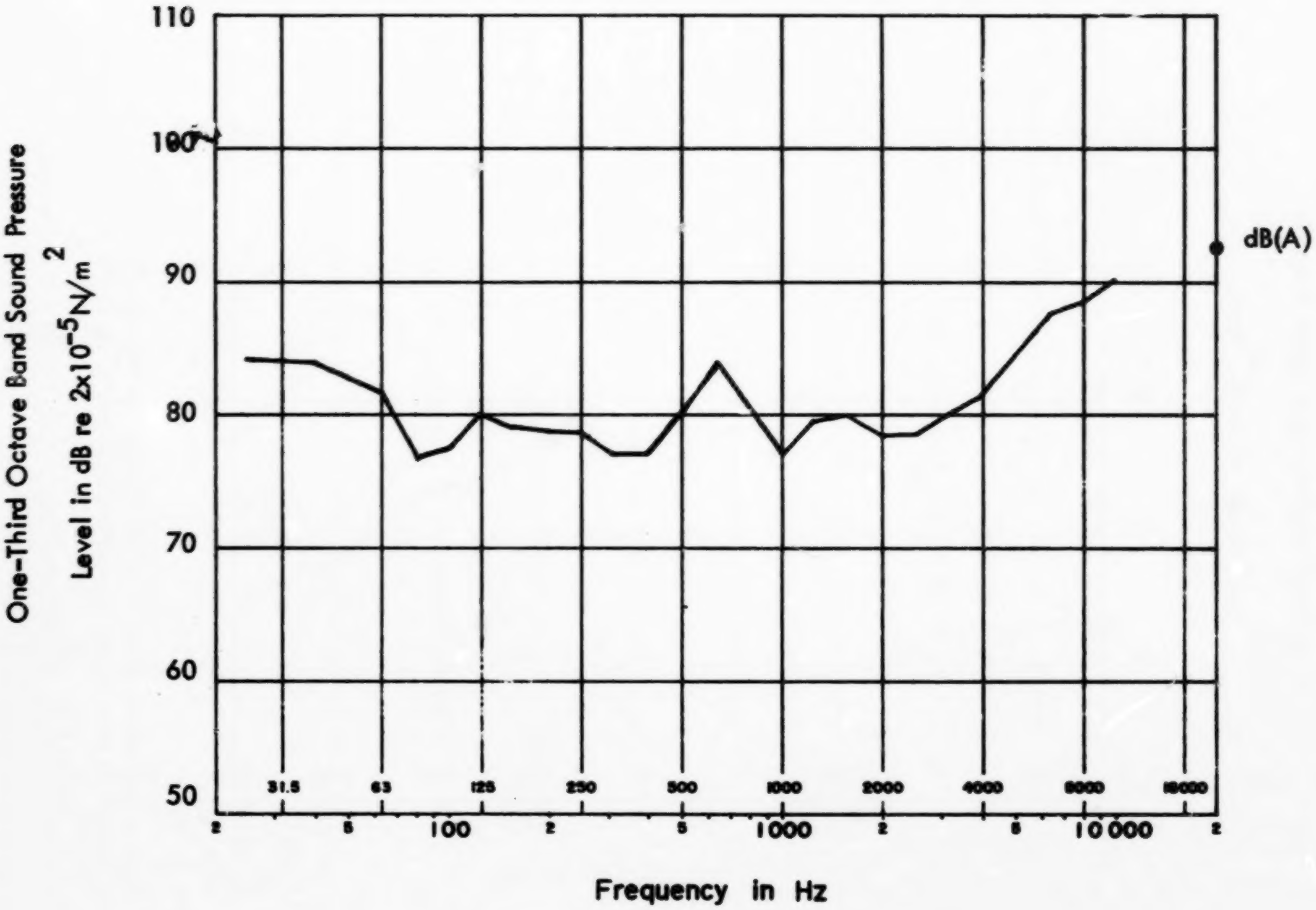


Figure 3.4.2-5. One-Third Octave Band Sound Pressure Levels Measured near Two Reciprocating Compressors in an Automobile Assembly Plant.

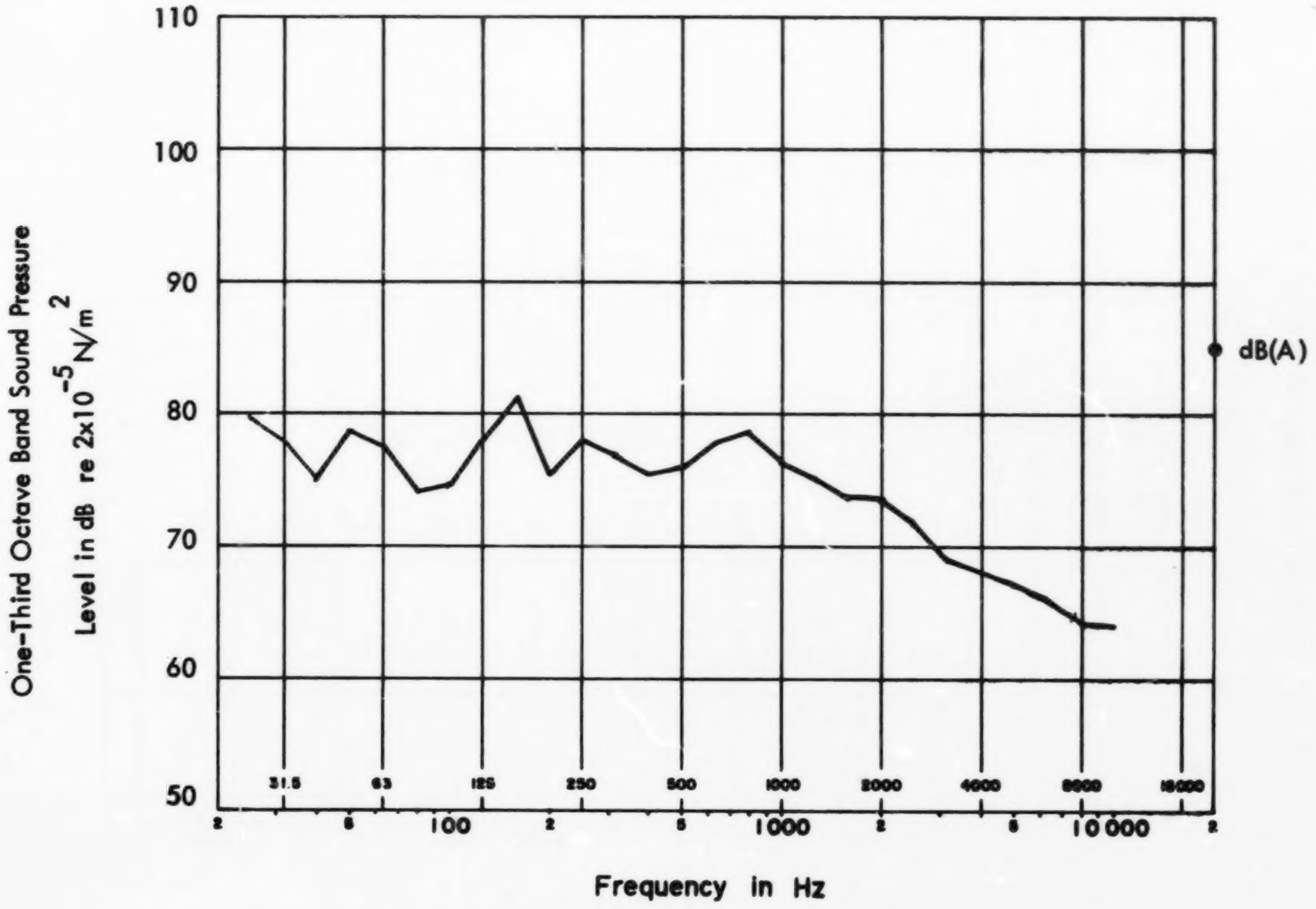


Figure 3.4.2-6. One-Third Octave Band Sound Pressure Levels Measured near A Typical Air Blowing Operation an an Automobile Assembly Plant.

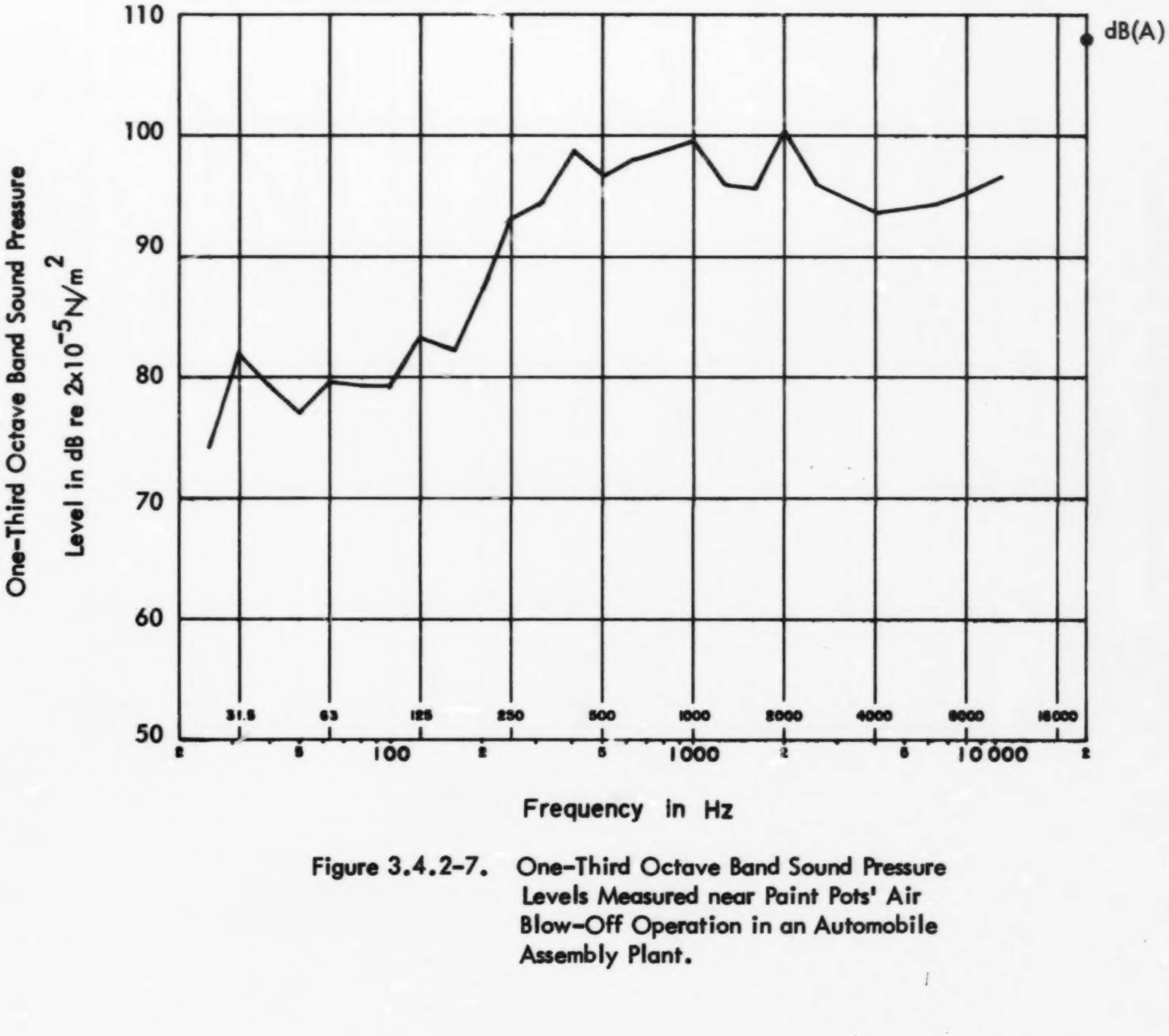


Figure 3.4.2-7. One-Third Octave Band Sound Pressure Levels Measured near Paint Pots' Air Blow-Off Operation in an Automobile Assembly Plant.

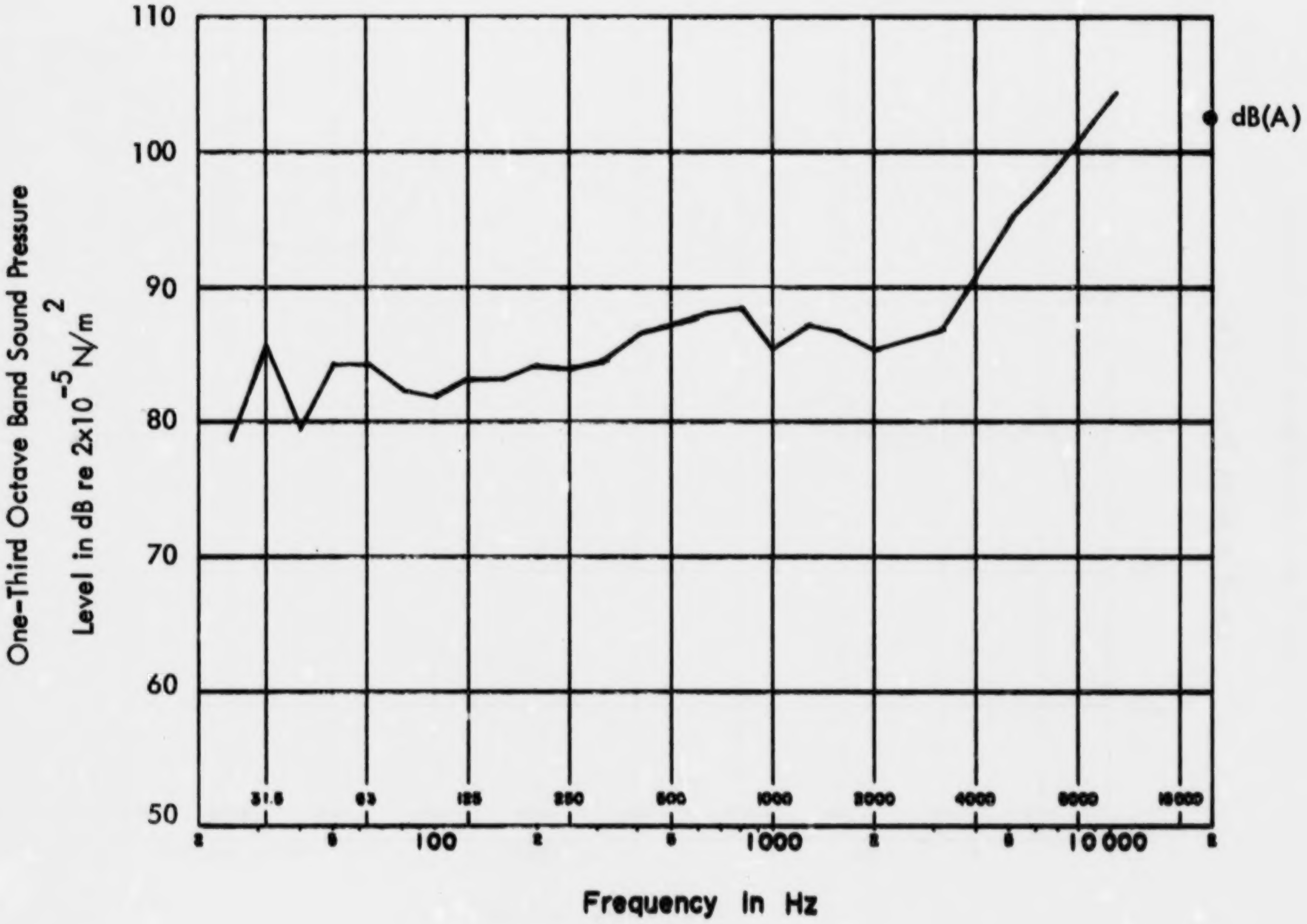


Figure 3.4.2-8. One-Third Octave Band Sound Pressure Levels Measured Below A Roof-Mounted Exhaust Blower in an Automobile Assembly Plant.

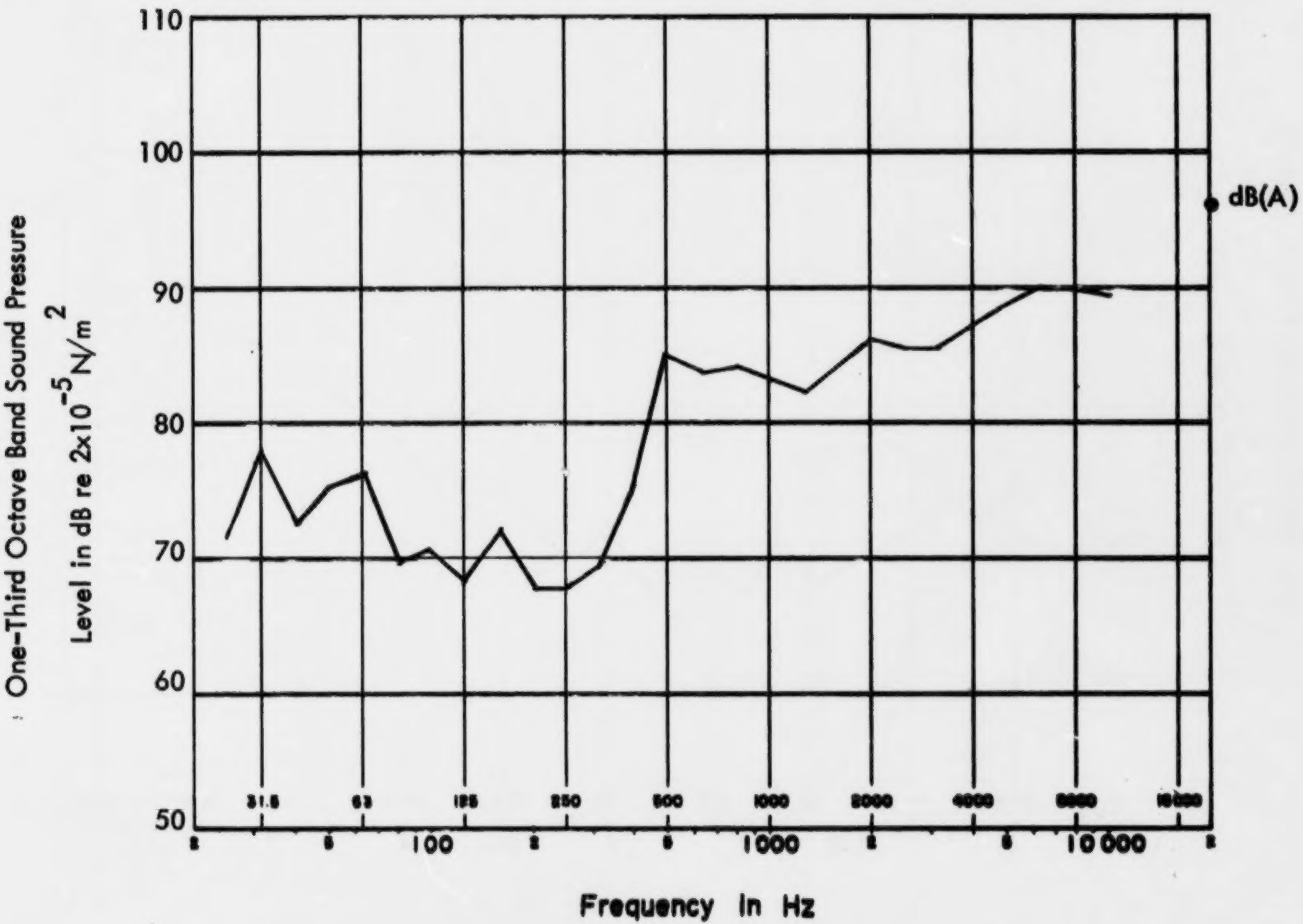


Figure 3.4.2-9. One-Third Octave Band Sound Pressure Levels Measured Near a Body Blow-Off Operation After Car Wash in an Automobile Assembly Plant.

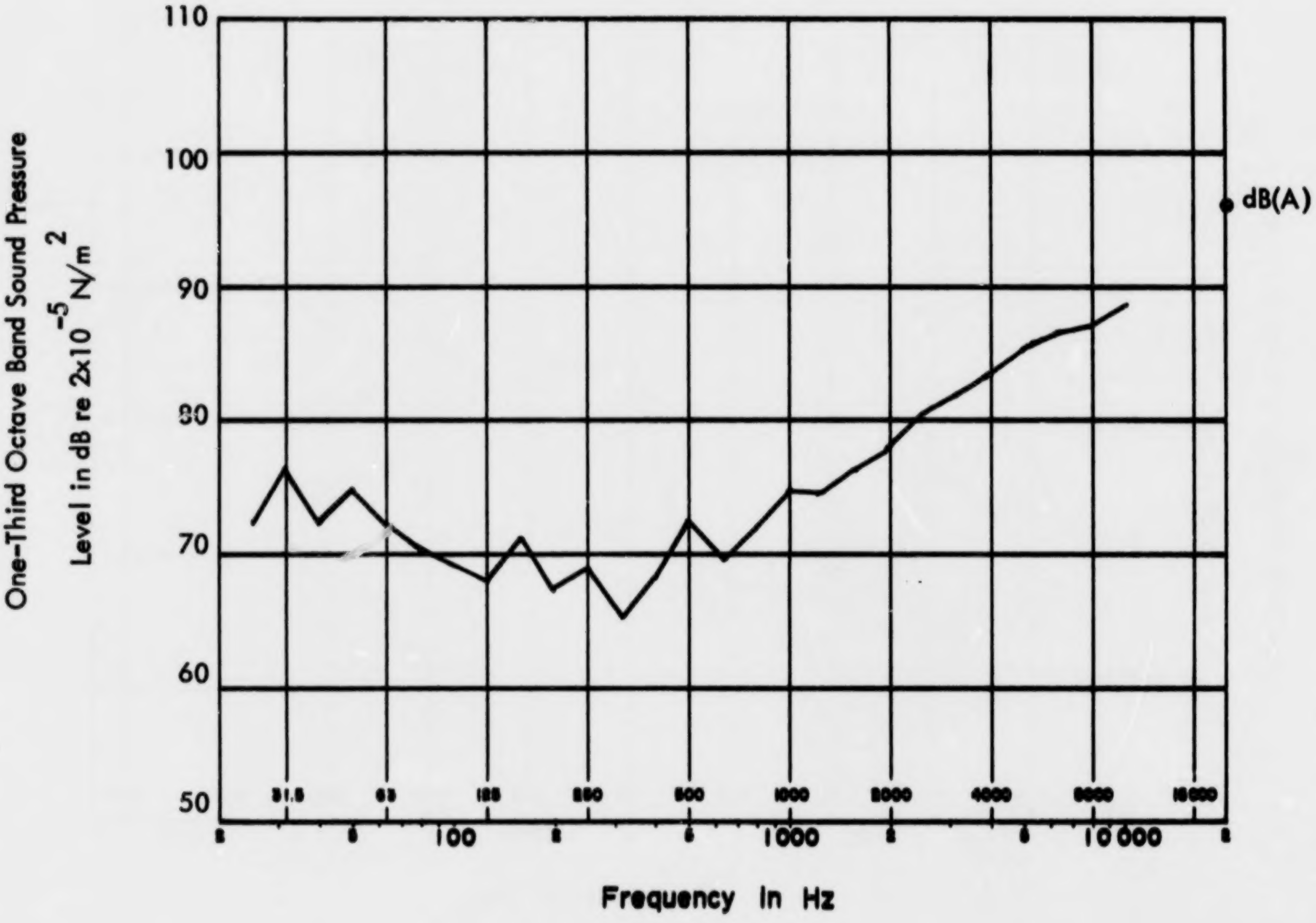


Figure 3.4.2-10. One-Third Octave Band Sound Pressure Levels Measured During an Engine Drop Operation (Pneumatic Impact Wrenches) in an Automobile Assembly Plant.

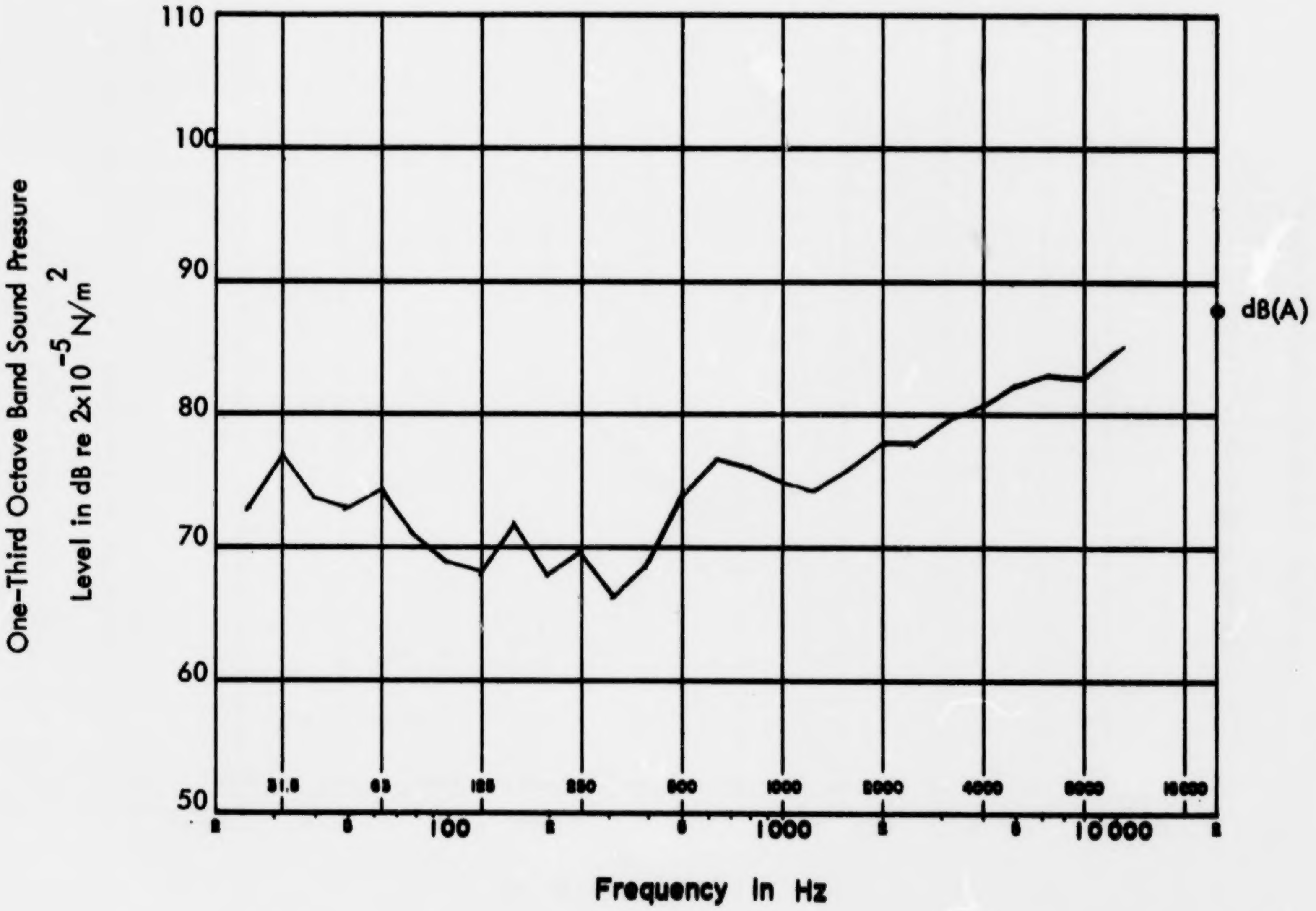


Figure 3.4.2-11. One-Third Octave Band Sound Pressure Levels Measured During Engine Drop Operation (Pneumatic Hoist) in an Automobile Assembly Plant.

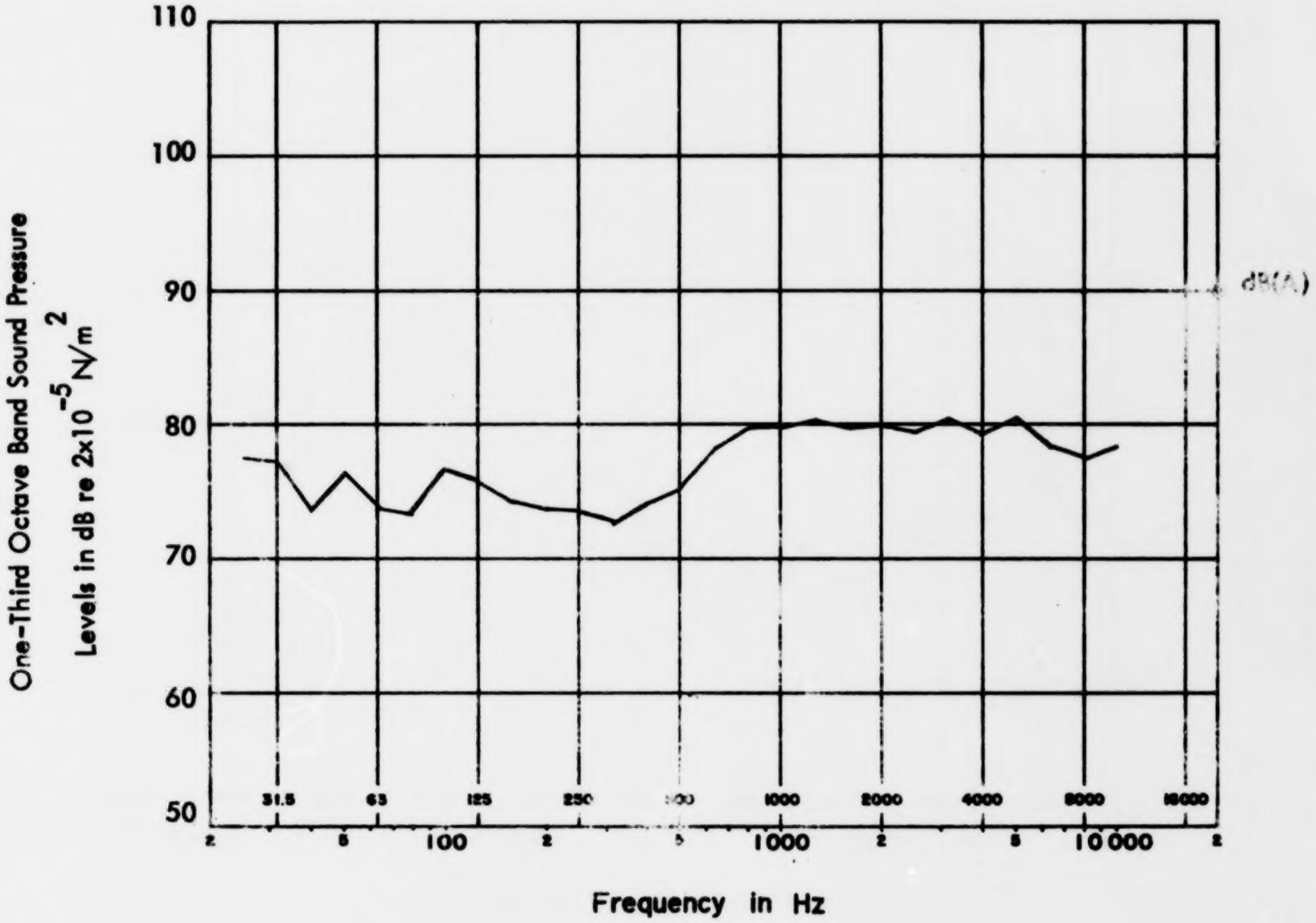
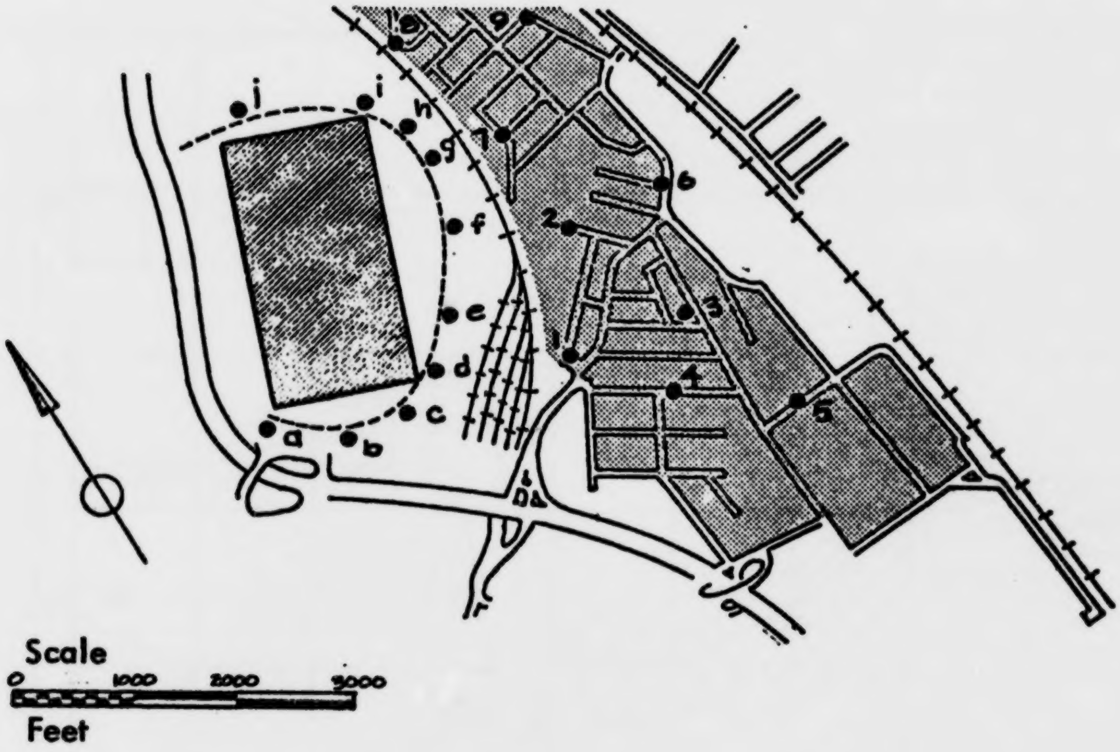


Figure 3.4.2-12. One-Third Octave Band Sound Pressure Levels Measured near a Metal Finishing Operation in an Autombile Assembly Plant.



	Community Noise Levels in dB(A)								
	1	2	3	4	5	6	7	8	9
Weekend	47	43	49	45	43	47	45	48	47
Weekday	50	48	50	49	47	54	50	53	50
Weeknight	51	50	50	50	47	52	48	54	48

	Plant Property Line Noise Levels in dB(A)									
	a	b	c	d	e	f	g	h	i	j
Weekend	54	47	46	46	47	54	54	49	54	46
Weekday	58	57	55	53	54	62	57	54	55	54
Weeknight	57	57	56	51	53	58	55	53	54	54

Key

▬	Industrial Noise Source
----------	Plant Property Line
▨	Residential Area
┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 3.4.3-1 Automobile Assembly Plant Community

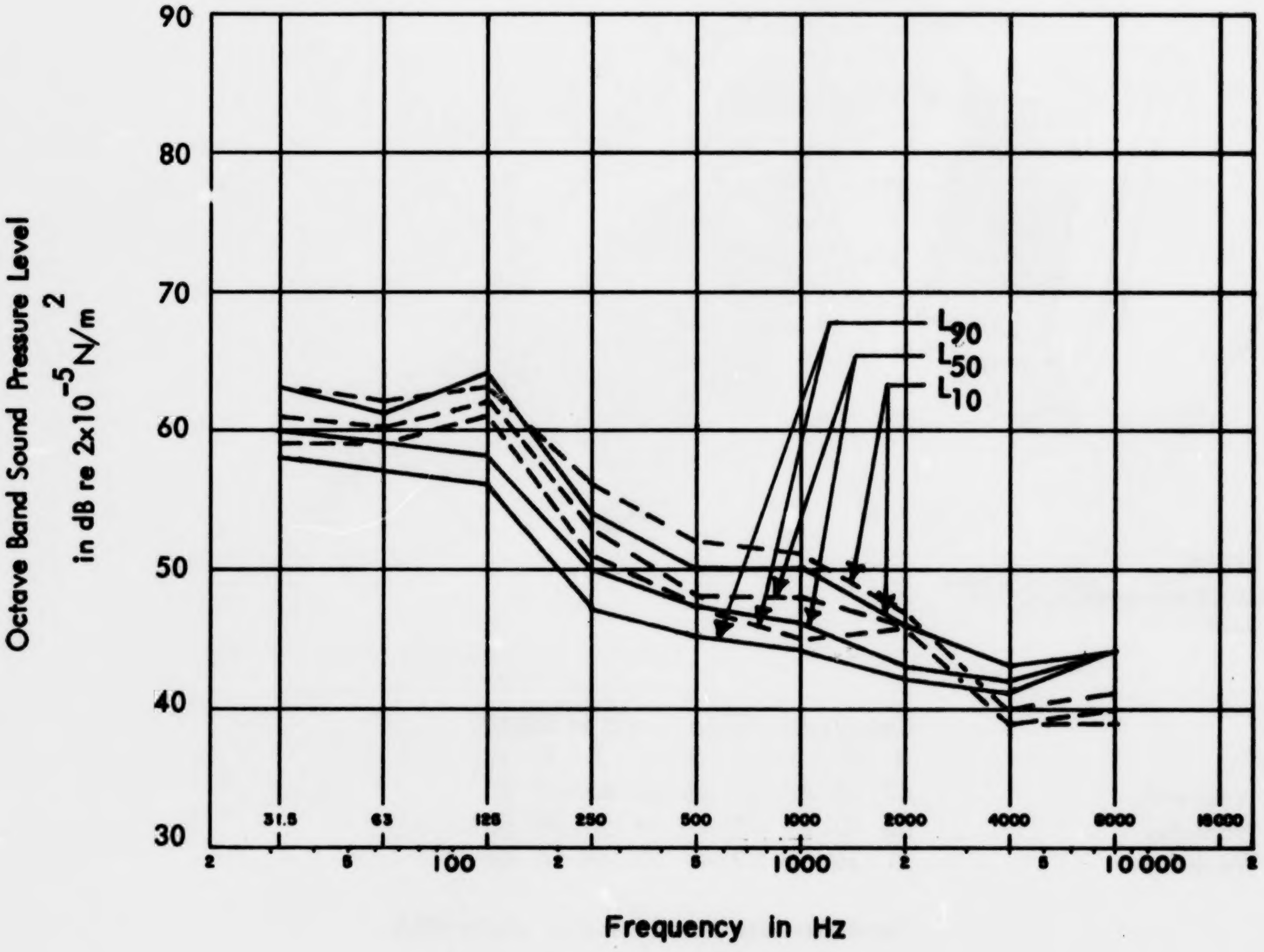


Figure 3.4.3-2. Automobile Assembly Plant Location 1

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

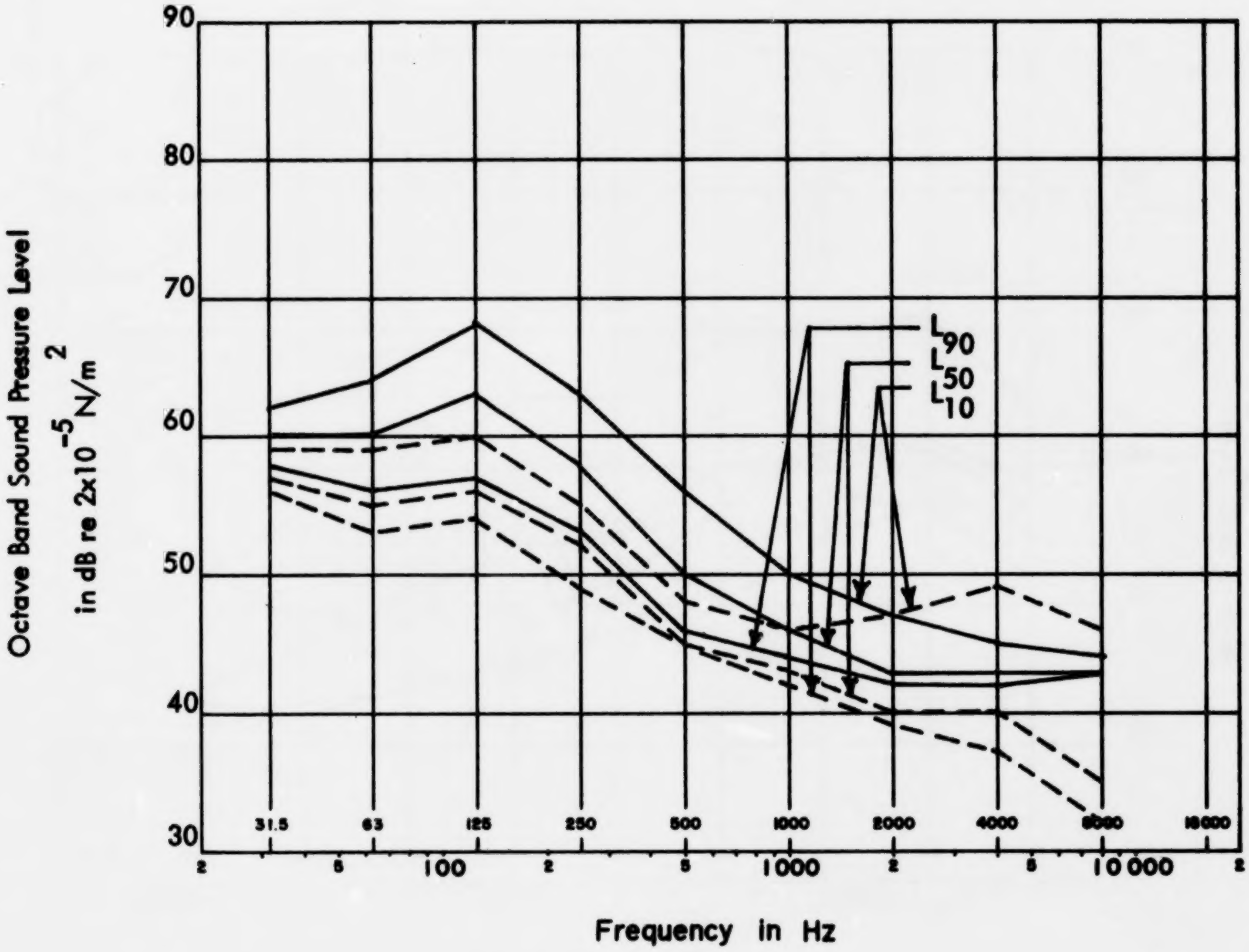


Figure 3.4.3-3. Automobile Assembly Plant Location 2

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – – Nighttime

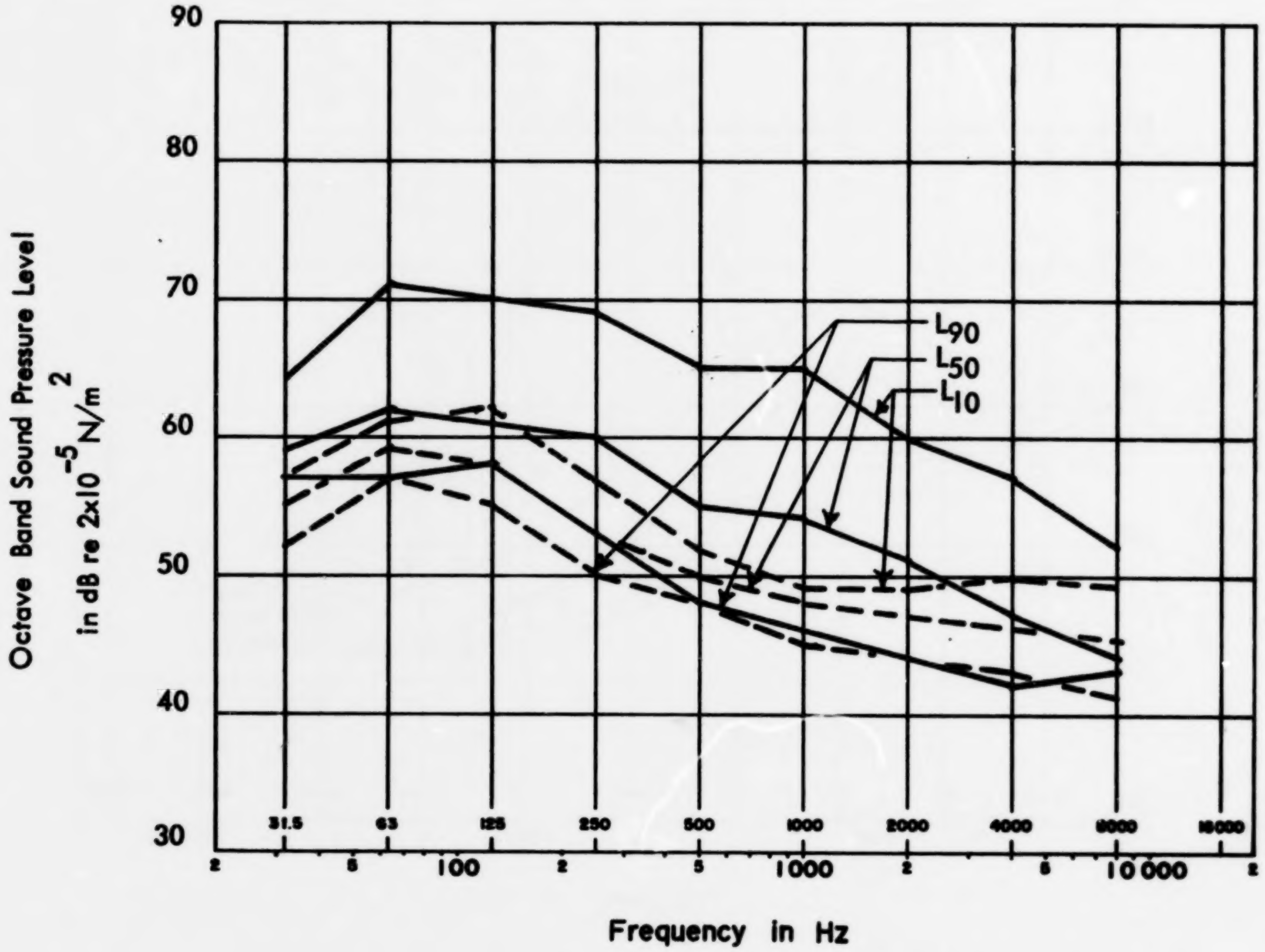


Figure 3.4.3–4. Automobile Assembly Plant Location 3.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

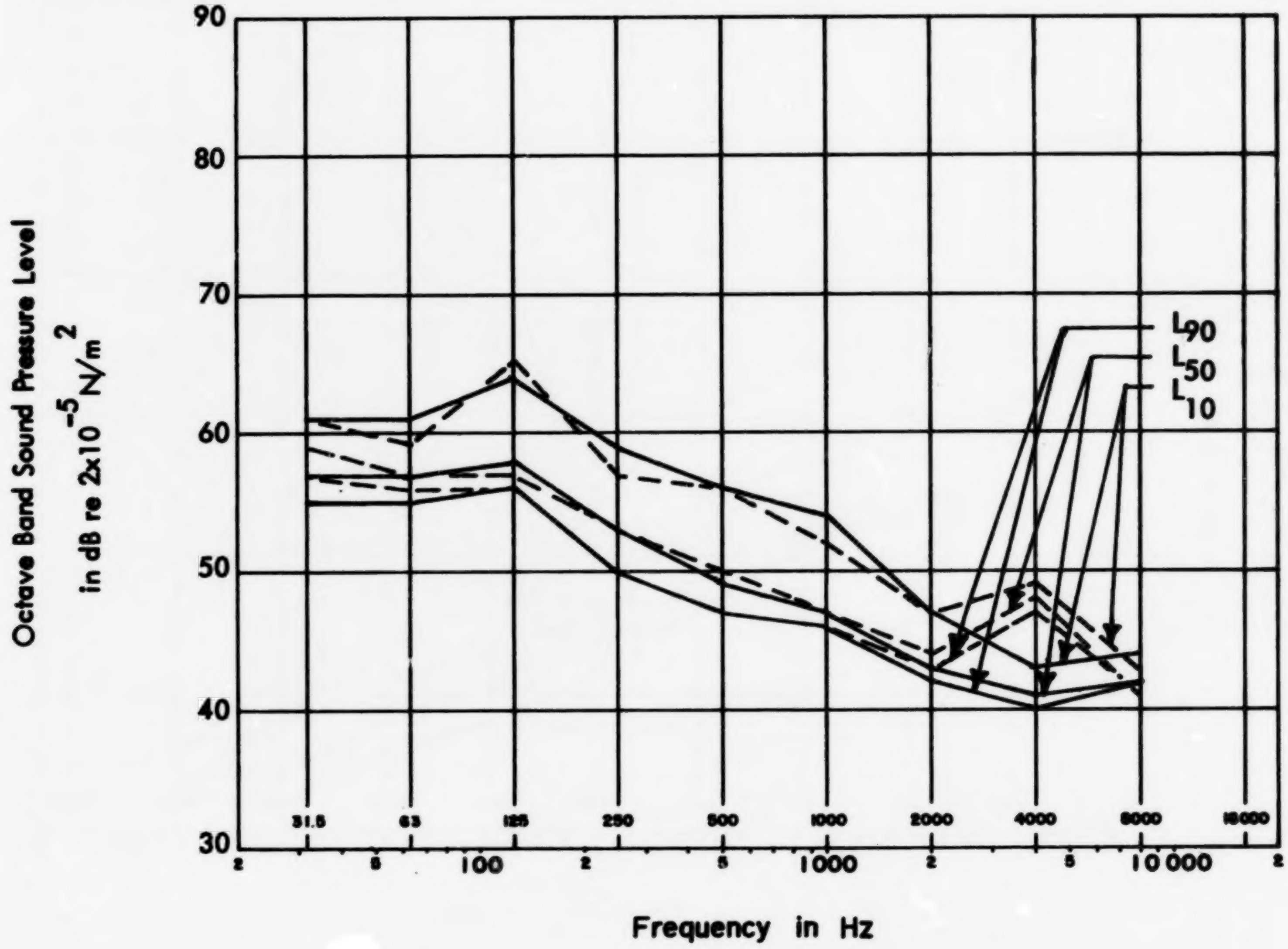


Figure 3.4.3-5. Automobile Assembly Plant Location 4

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 with One Second Integration Time.

———— Daytime

– – – – Nighttime

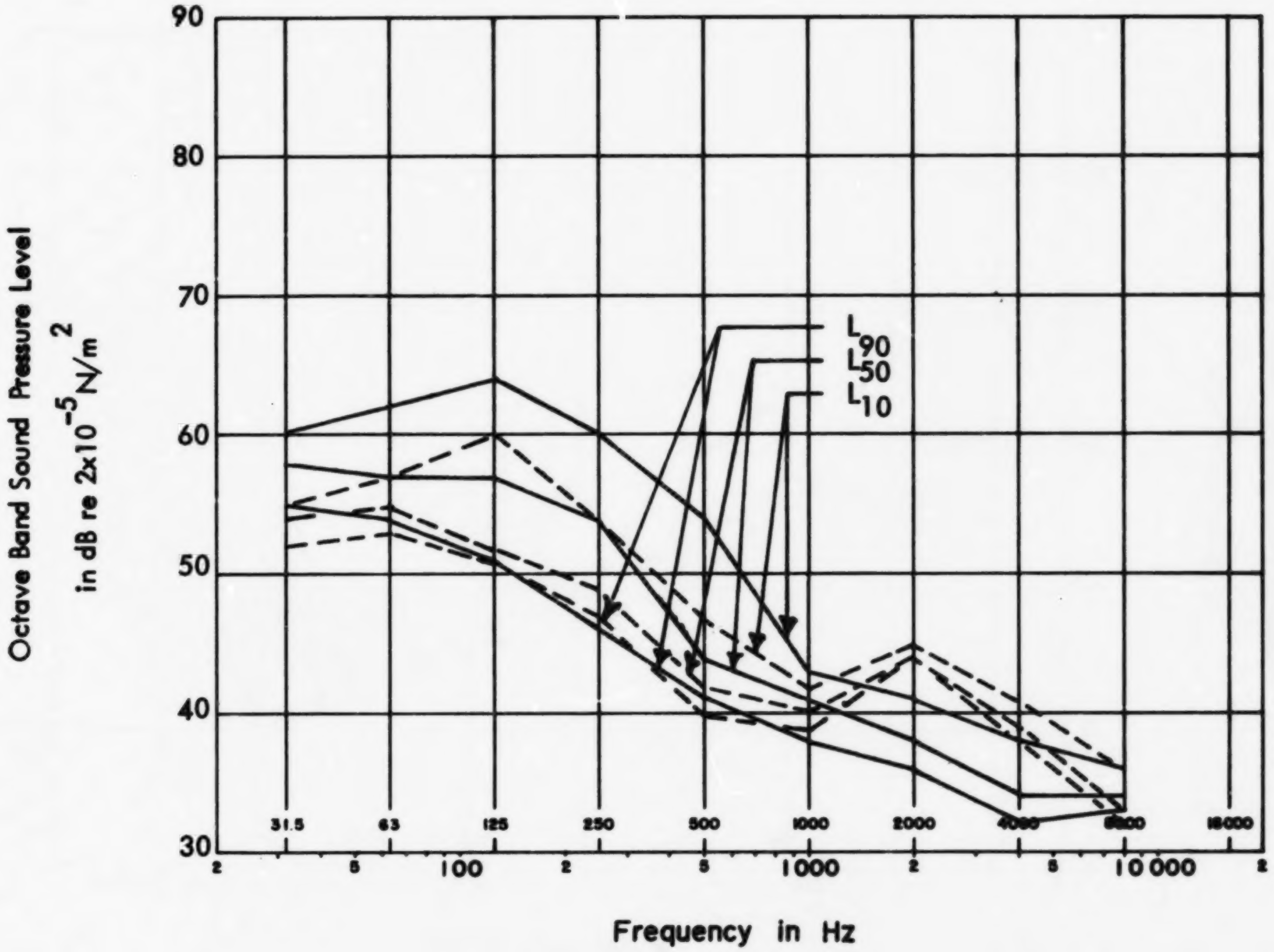


Figure 3.4.3-6. Automobile Assembly Plant Location 5

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

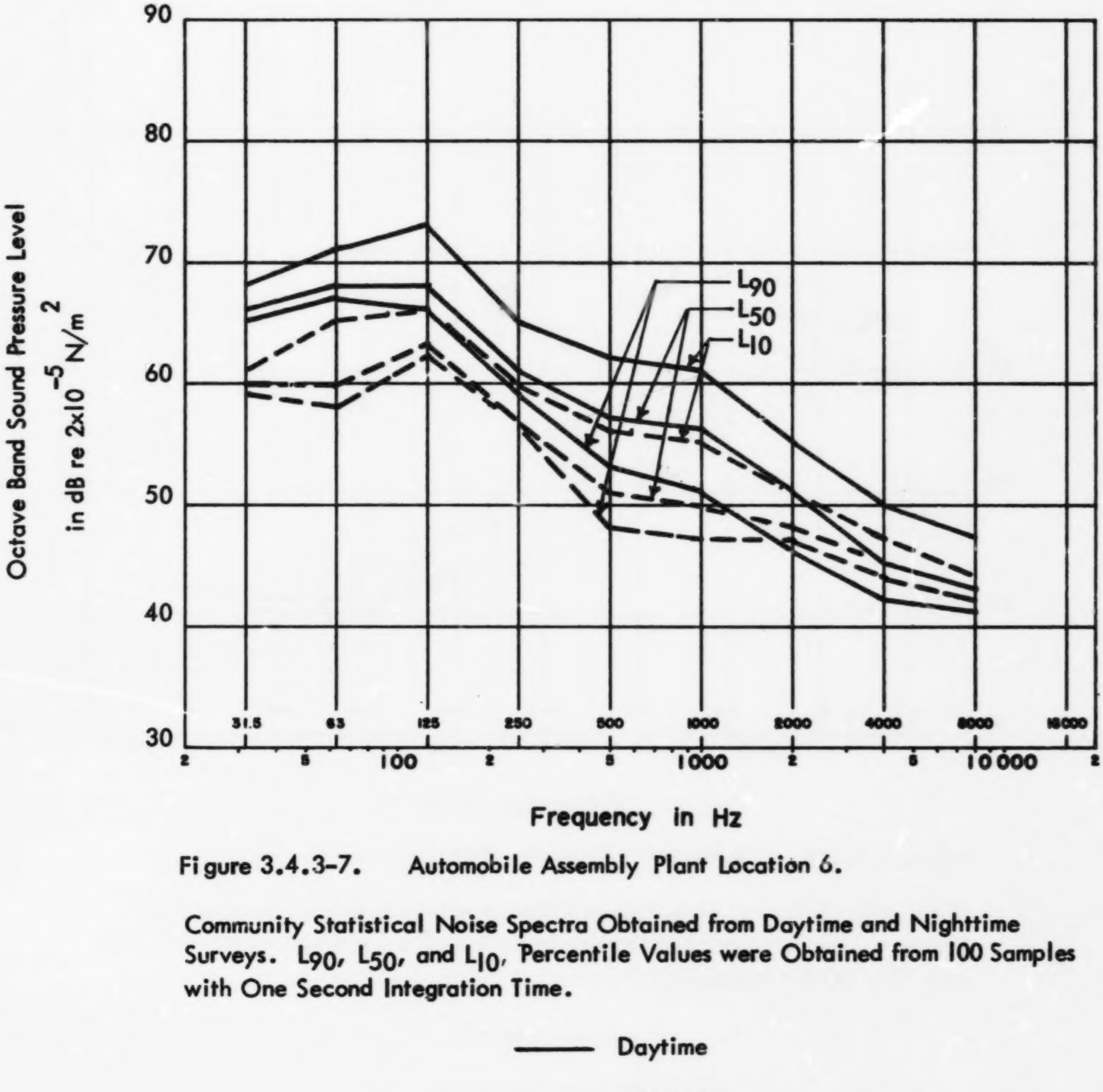


Figure 3.4.3-7. Automobile Assembly Plant Location 6.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10}, Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

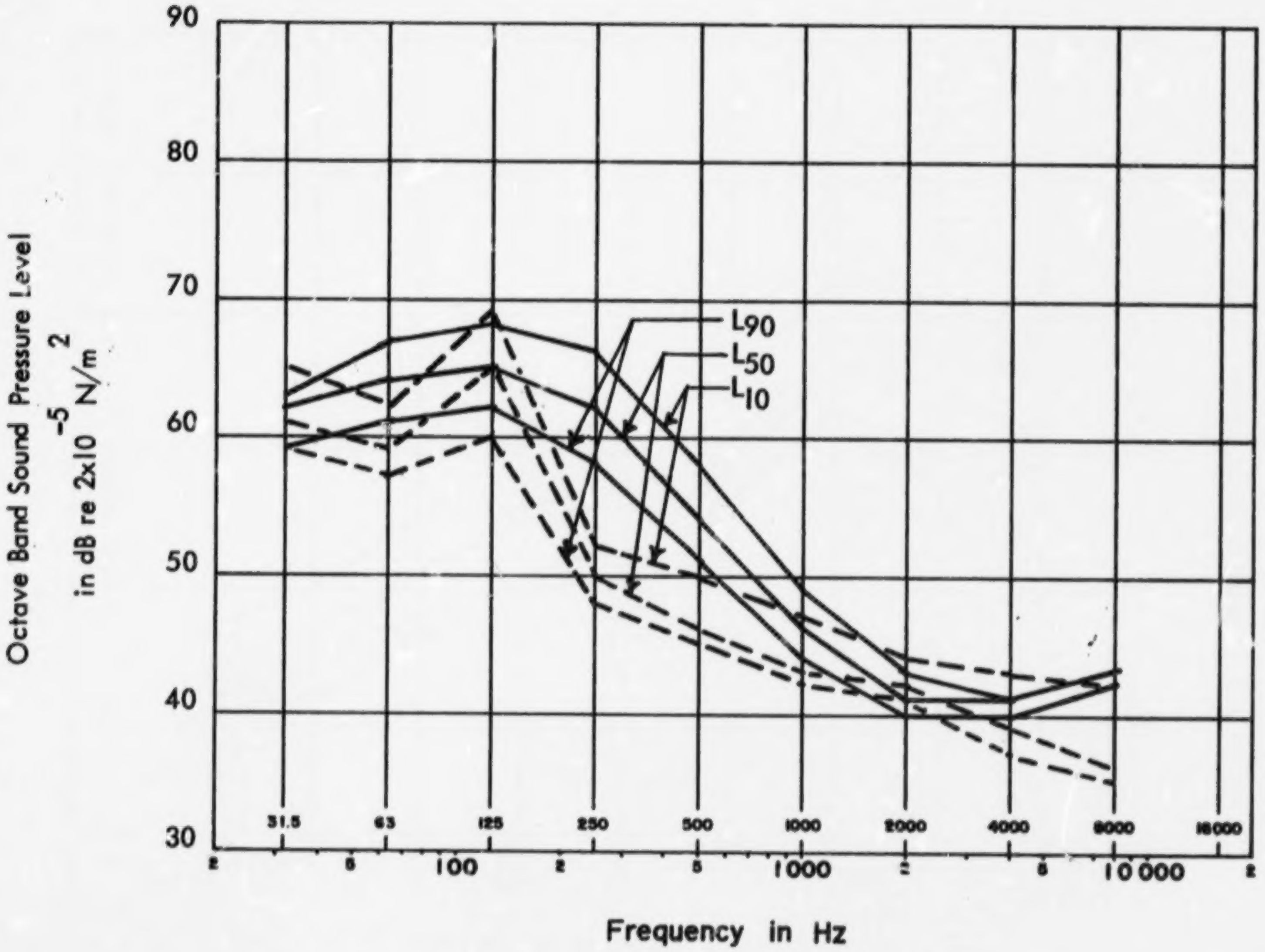


Figure 3.4.3-8. Automobile Assembly Plant Location 7.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

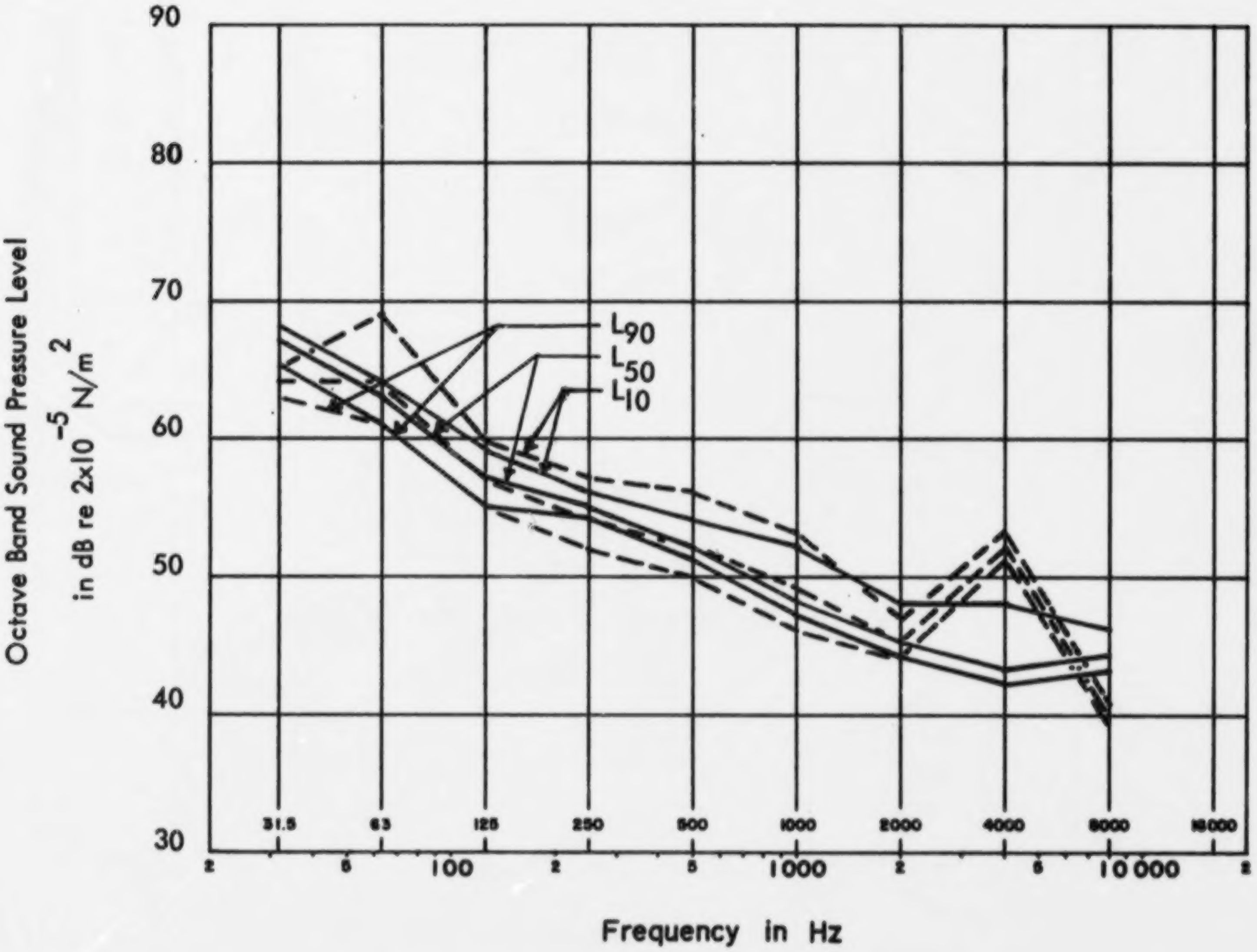


Figure 3.4.3-9. Automobile Assembly Plant Location 8.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

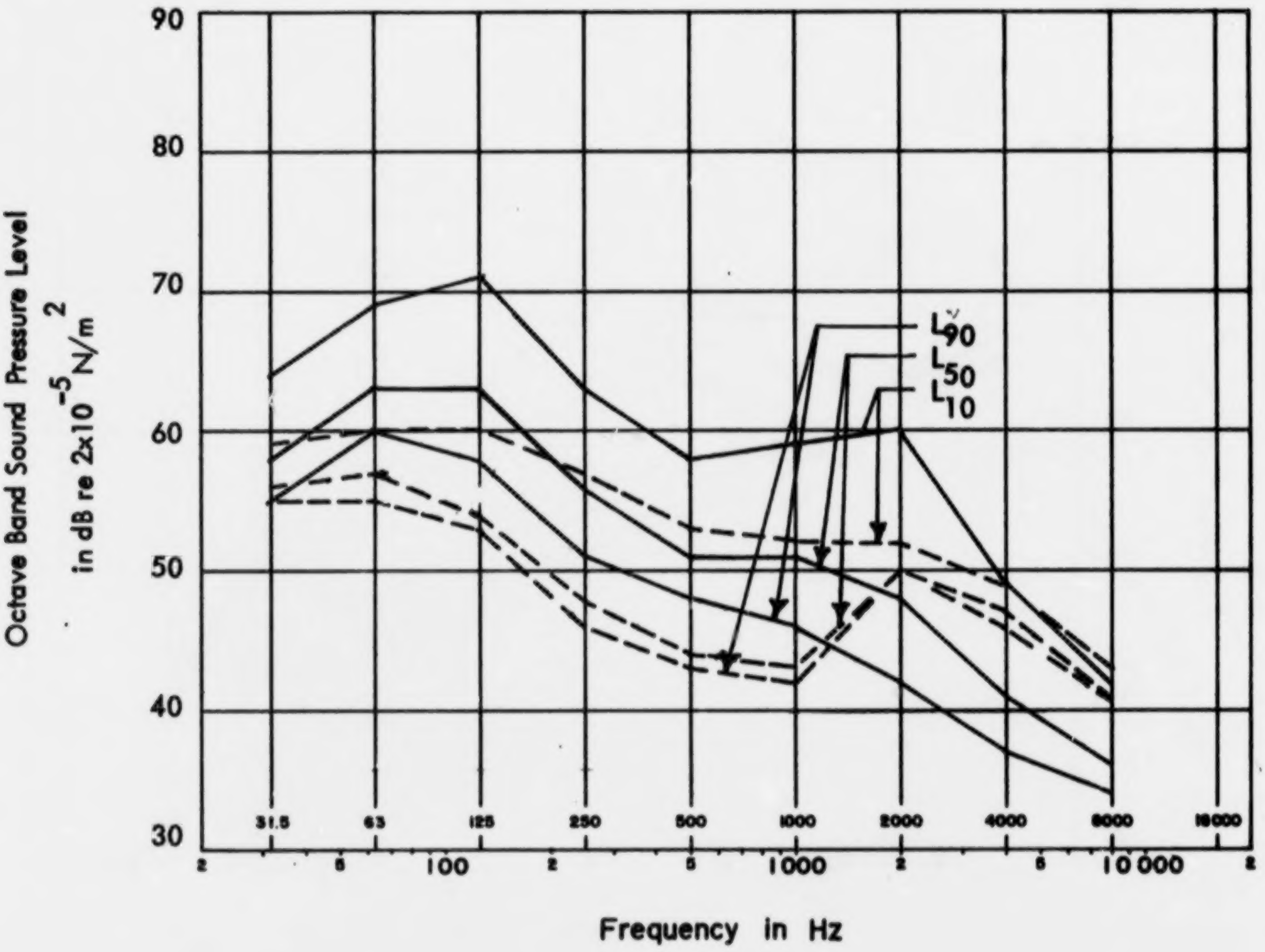


Figure 3.4.3-10. Automobile Assembly Plant Location 9

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——————— Daytime

— — — —· Nighttime

A-Weighted Noise Level in dB re $2x10^{-5} N/m^2$

```
50 **
51 ***************
52 ************
53 ********
54 *******
55 ****
56 *
57 *
58
59.
60
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5} N/m^2$

```
50
51
52 ******
53 ***************
54 ****************
55 *****
56 ******
57 **
58
59
60
```

Number of Occurrences
Nighttime

Figure 3.4.3-11. Automobile Assembly Plant Location 1.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51 *
52 *******
53 ******
54 ********
55 **********
56 ******
57 **
58 ******
59
60
61
62
63 ***
64 *
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51 ************************************
52 ************
53 **
54
55
```

Number of Occurrences
Nighttime

Figure 3.4.3-12. Automobile Assembly Plant Location 2.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5}N/m^2

```
50
51
52 **
53 *
54 *******
55 ****
56 ****
57 ***
58 *
59 *
60 ****
61 *
62 **
63 **
64 *
65 ****
66 *
67 ****
68 **
69 ****
70
71 *
72 *
73
74
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5}N/m^2

```
45
46
47
48
49 *
50 **********************
51 ******
52 **********
53 *****
54 **
55 *
56 *
57
58 *
59 *
60
```

Number of Occurrences
Nighttime

Figure 3.4.3-13. Automobile Assembly Plant Location 3.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
50 ****
51 *************
52 **********
53 *********
54 **********
55 ***
56
57 *
58
59
60
```

Number of Cccurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
45
46
47
48
49 ******
50 ***************************
51 **********
52
53 ****
54 *
55 *
56 *
57
58
59
60
```

Number of Occurrences
Nighttime

Figure 3.4.3-14. Automobile Assembly Plant Location 4.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
45
46
47
48 ***********
49 ****************
50 ***********
51 *****
52 ***
53 *
54
55
56
57 *
58
59
60
61
62 *
63 *
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
45
46
47
48 *****************************
49 *******************
50
51 **
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.4.3-15. Automobile Assembly Plant Location 5.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51
52
53
54 *
55 ******
56 ****
57 **
58 ***
59 ********
60 ********
61 *****
62 ***
63 ***
64 ****
65 ***
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51
52 ****
53 ************
54 **********
55 **
56
57 ***
58 ****
59 *******
60
61
62
63 ****
64 **
65 **
66
67
68
69
70
```

Number of Occurrences
Nighttime

Figure 3.4.3-16. Automobile Assembly Plant Location 6.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
50
51
52
53
54 ***
55 ******
56 ********
57 *********
58 ********
59 ************
60 ***
61 *
62
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
45
46
47 ******************
48 ******************
49 ************
50
51 **
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.4.3-17. Automobile Assembly Plant Location 7.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
50
51
52
53
54 *****************
55 ****************
56 ***
57 *******
58 **
59
60 ***
61 **
62
63
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
50
51
52
53
54 ********************
55 *********
56 *********
57 ***
58 ******
59
60 *
61 *
62 *
63
64
65
```

Number of Occurrences
Nighttime

Figure 3.4.3-18. Automobile Assembly Plant Location 8.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2 \times 10^{-5} N/m^2$

```
50 *
51 ************
52 *******************
53 **
54 *****
55 *
56 ****
57 *
58 **
59 *
60
61 *
62
63
64
65
66
67
68
69
70
71 *
72
73
74
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2 \times 10^{-5} N/m^2$

```
50 ******************
51 *****************
52 ****
53 *
54 *
55 *
56
57
58 *
59 ****
60
61 *
62
63 **
64
65
```

Number of Occurrences
Nighttime

Figure 3.4.3-19. Automobile Assembly Plant Location 9.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

Table 3.4.3-1 - Intrusive (L_{10}) Noise Level (A-Weighted) Observed at Automobile Assembly Plant Community Locations During Day, Evening, and Nighttime Sampling Periods

	Noise Level dB(A)		
Location	Day	Evening	Night
1	55	58	52
	55		54
	52		56
			56
2	59	54	49
	55	55	52
	56		57
	52		52
3	69	64	54
	64	54	56
	56		57
	57		52
4	54	58	50
	58	56	53
	53		59
	55		52
5	52	52	50
	54	52	50
	55		49

	Noise Level dB(A)		
Location	Day	Evening	Night
6	64	59	53
	64	58	54
	65		63
	58		
7	60	57	49
	51	52	49
			55
8	57	62	59
	56		59
			58
9	54	58	58
	62	49	48
	64		54
	62		

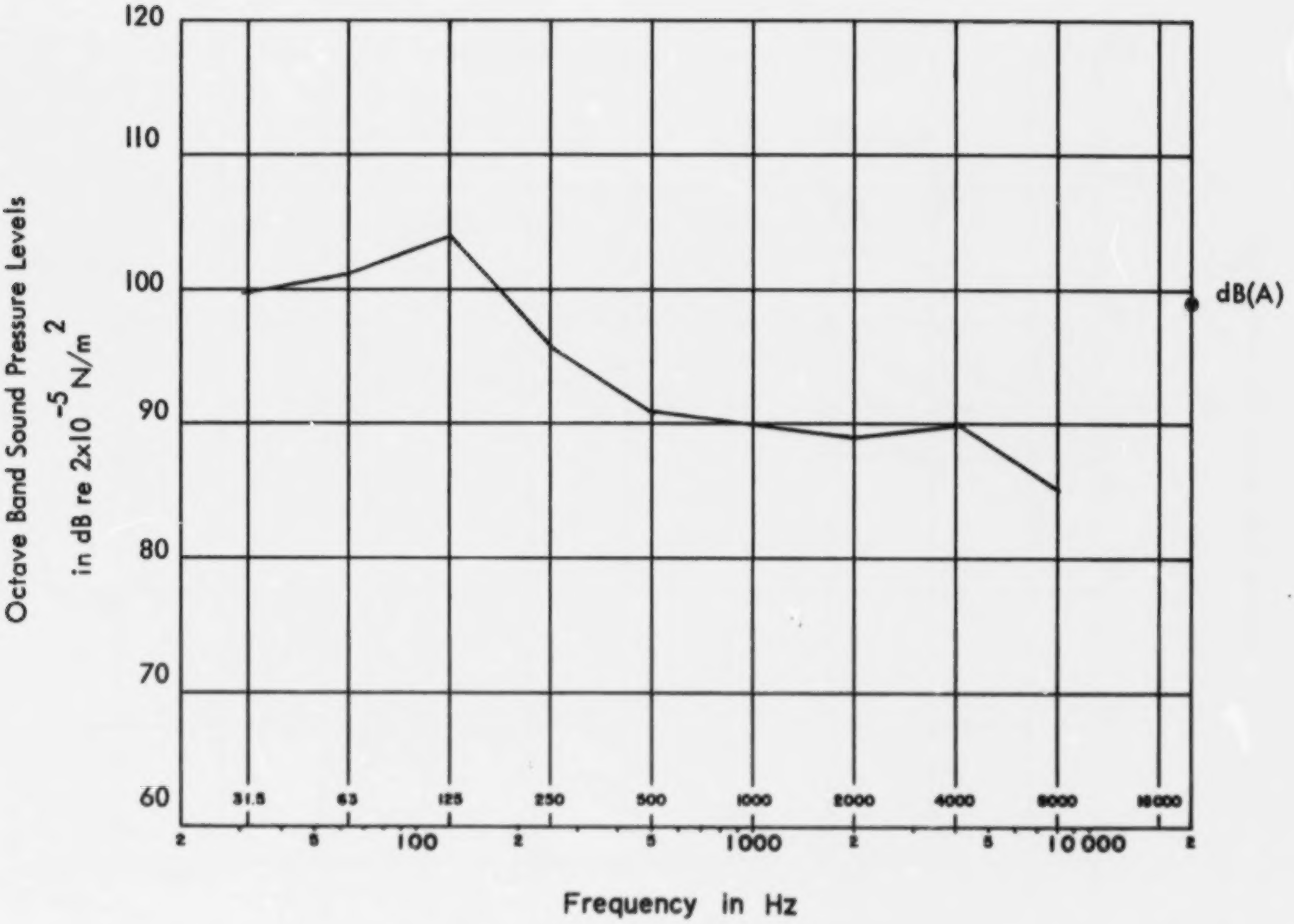


Figure 3.5.2-1. Octave Band Sound Pressure Levels Measured at the Air Compressor Section in a Can Manufacturing Plant.

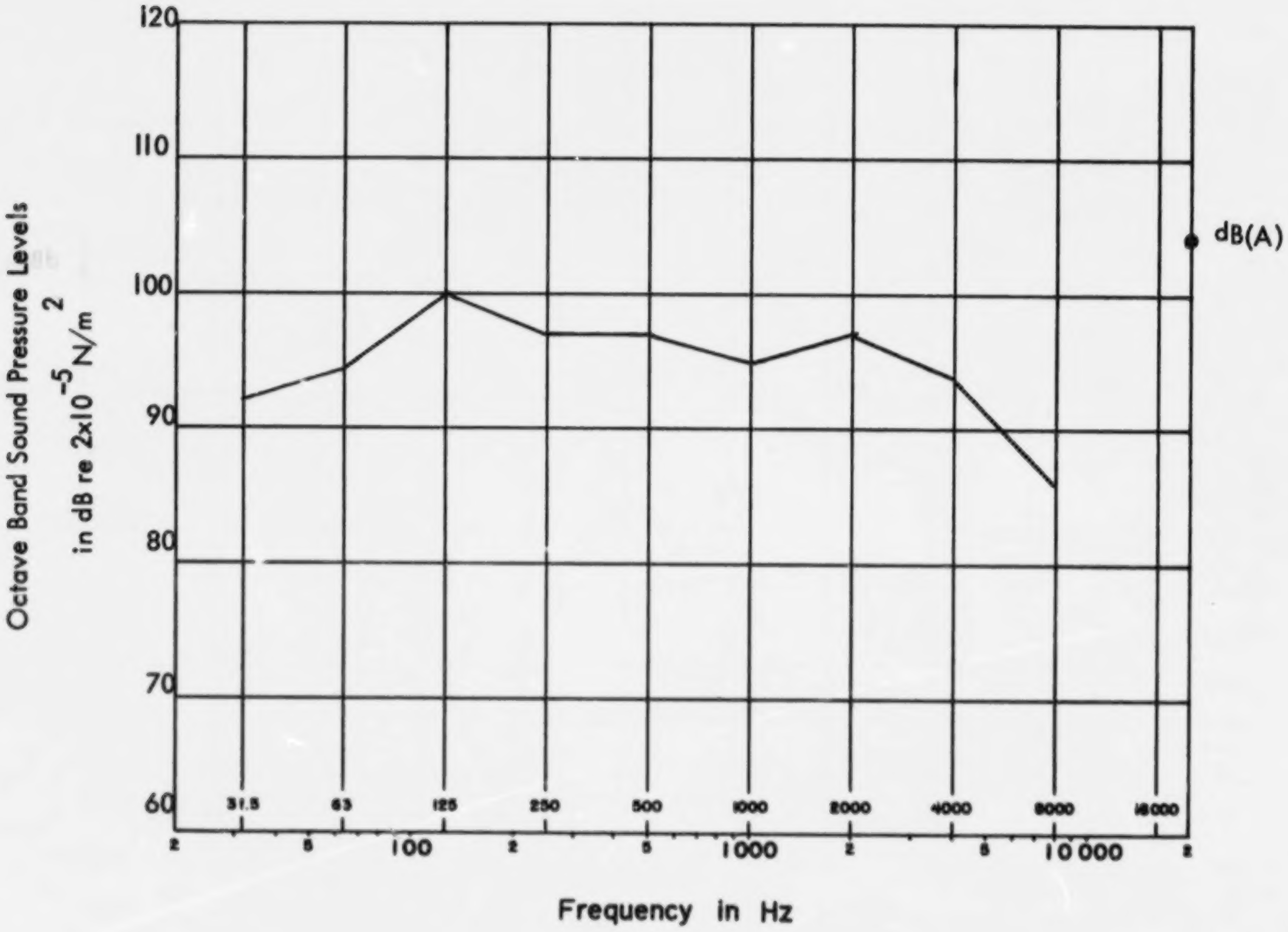


Figure 3.5.2-2. Octave Band Sound Pressure Levels Measured near a Ring Pull Punch Press in a Can Manufacturing Plant.

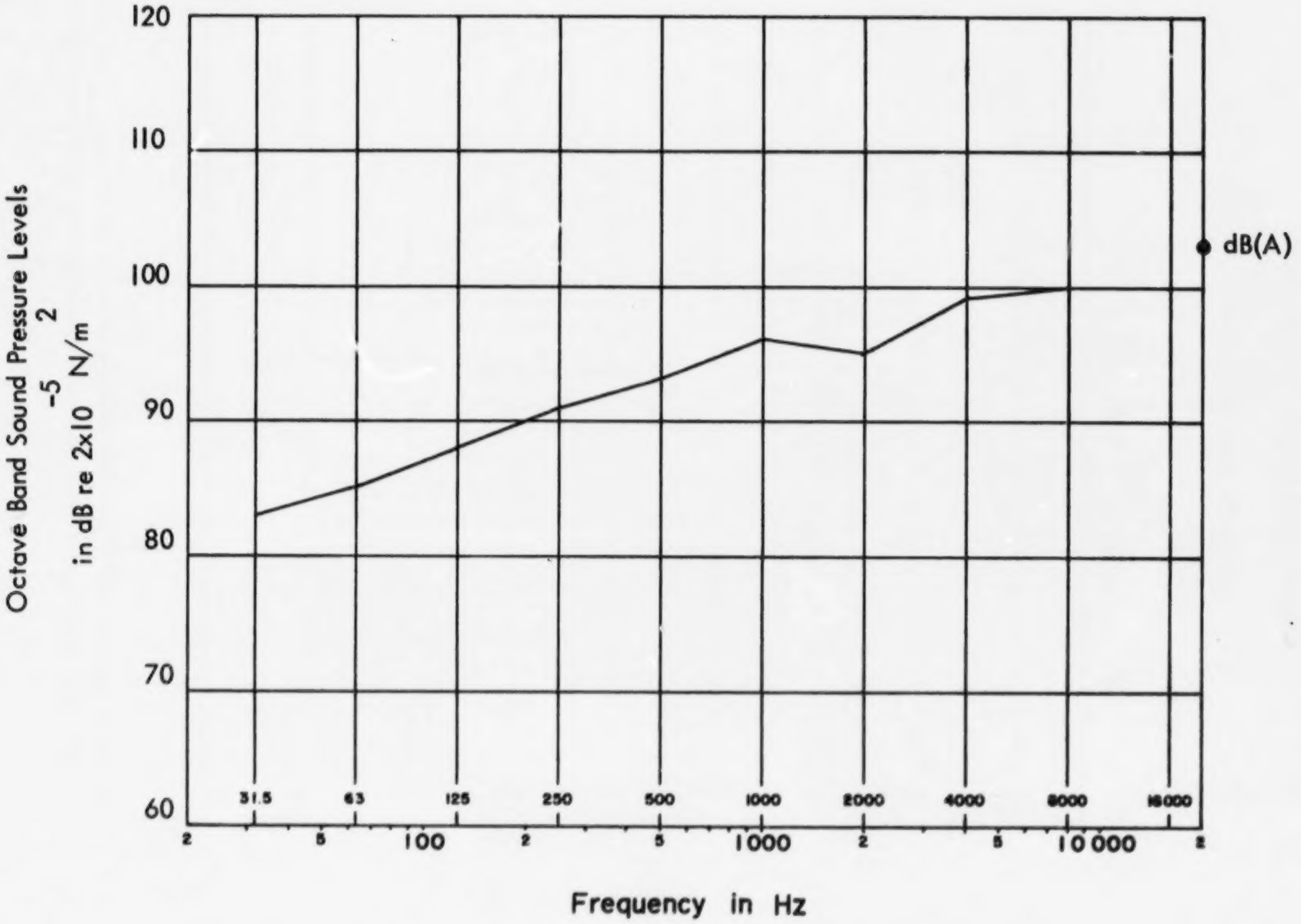


Figure 3.5.2-3. Octave Band Sound Pressure Levels Measured near the Internal Lacquer Spray Line in a Can Manufacturing Plant.

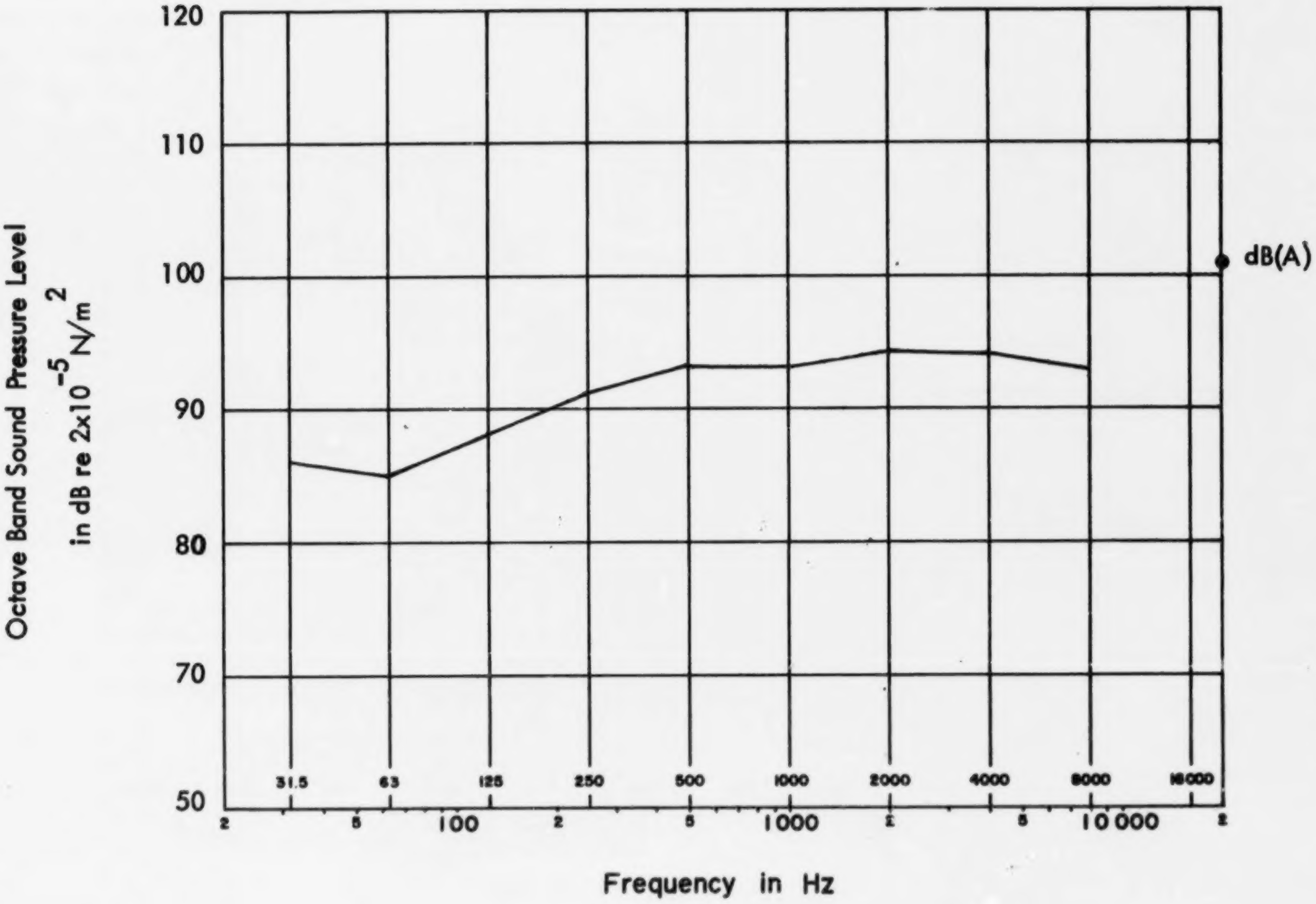


Figure 3.5.2-4. Octave Band Sound Pressure Levels of Body Maker-Slitter (200 Cans/Min.) in a Can Manufacturing Plant.

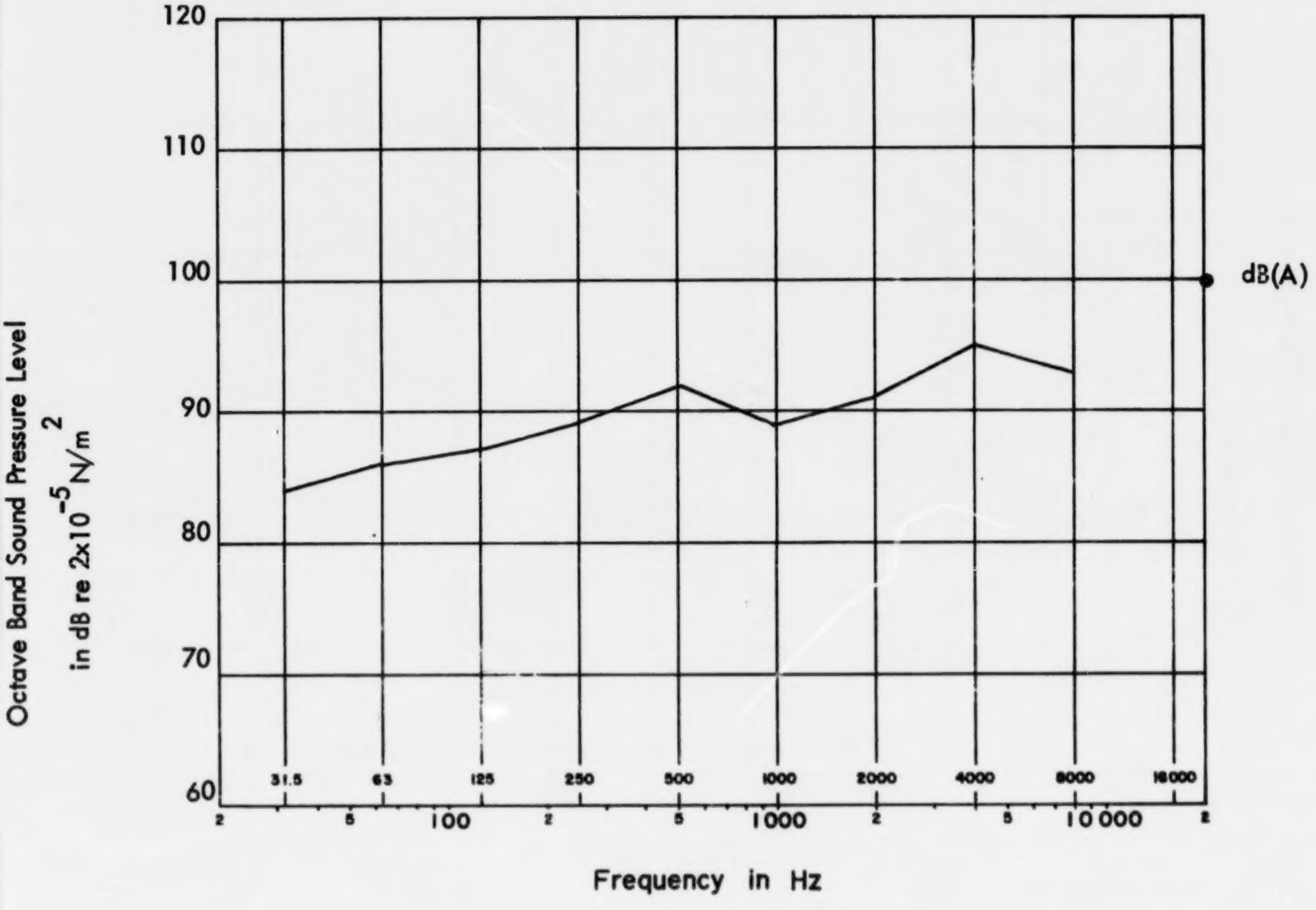


Figure 3.5.2-5. Octave Band Sound Pressure Levels of F langer Line in a Can Manufacturing Plant.

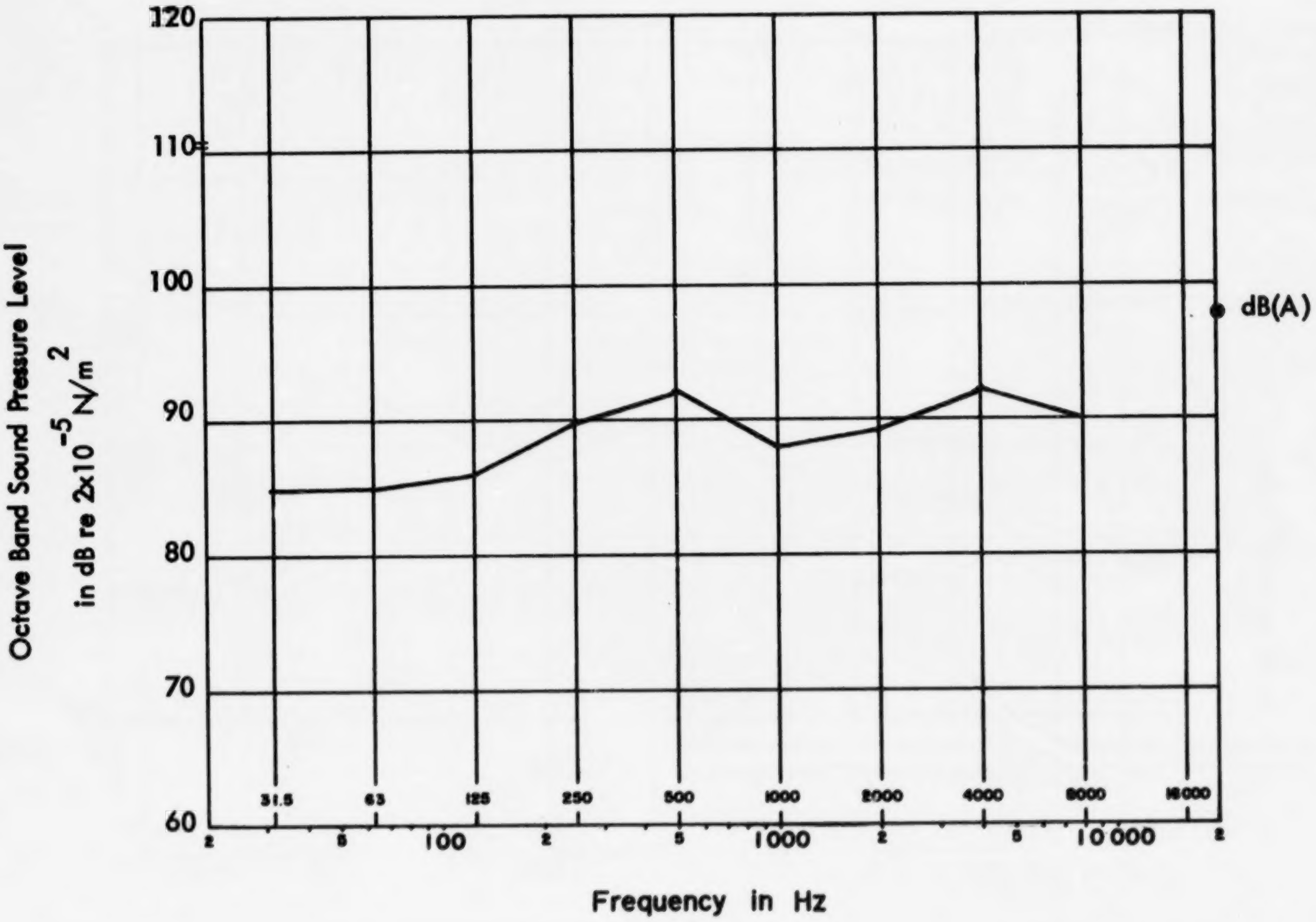


Figure 3.5.2-6. Octave Band Sound Pressure Levels of a Beader Line in a Can Ma nufacturing Plant.

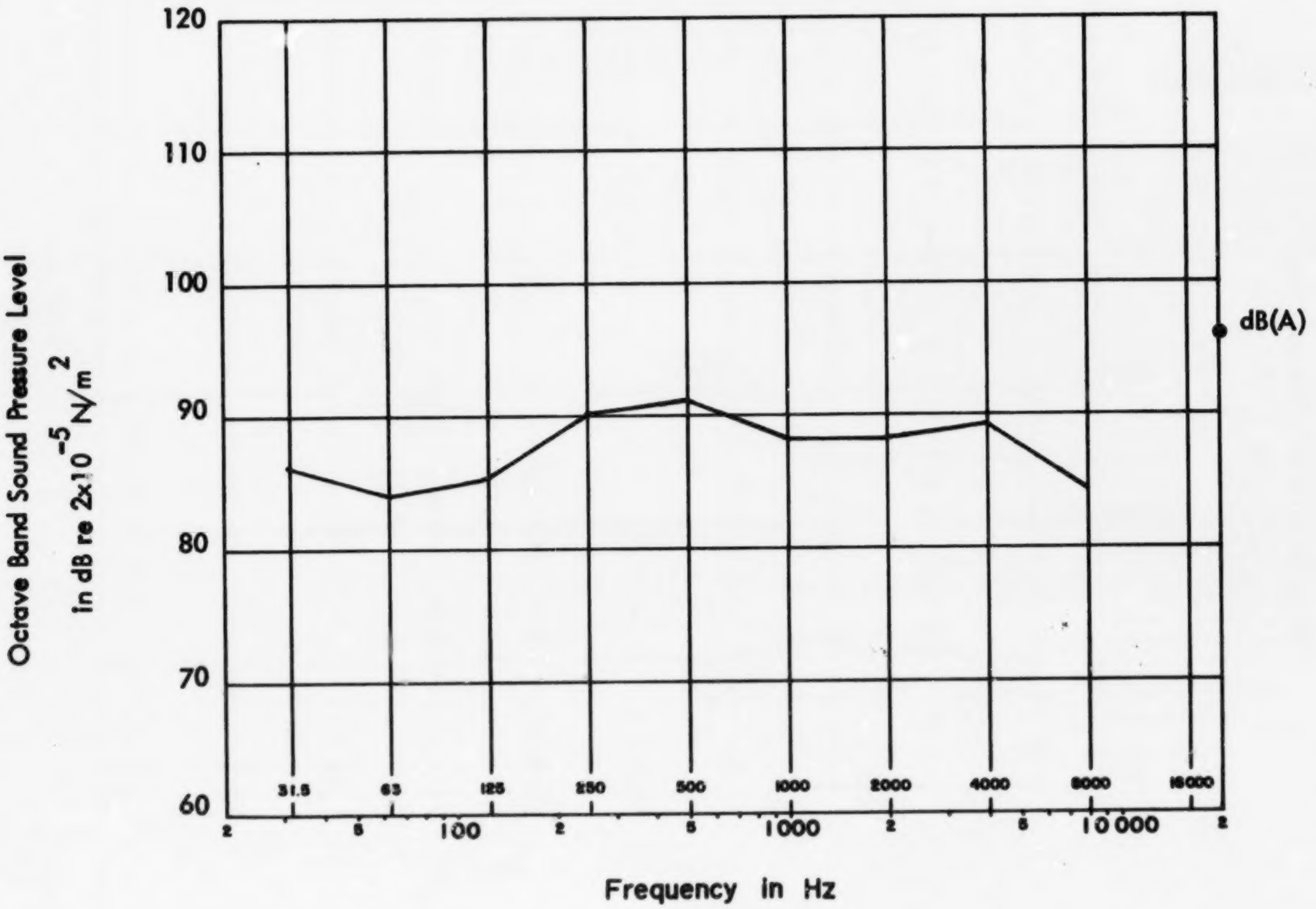


Figure 3.5.2-7. Octave Band Sound Pressure Levels of an Air Test Line in a Can Manufacturing Plant.

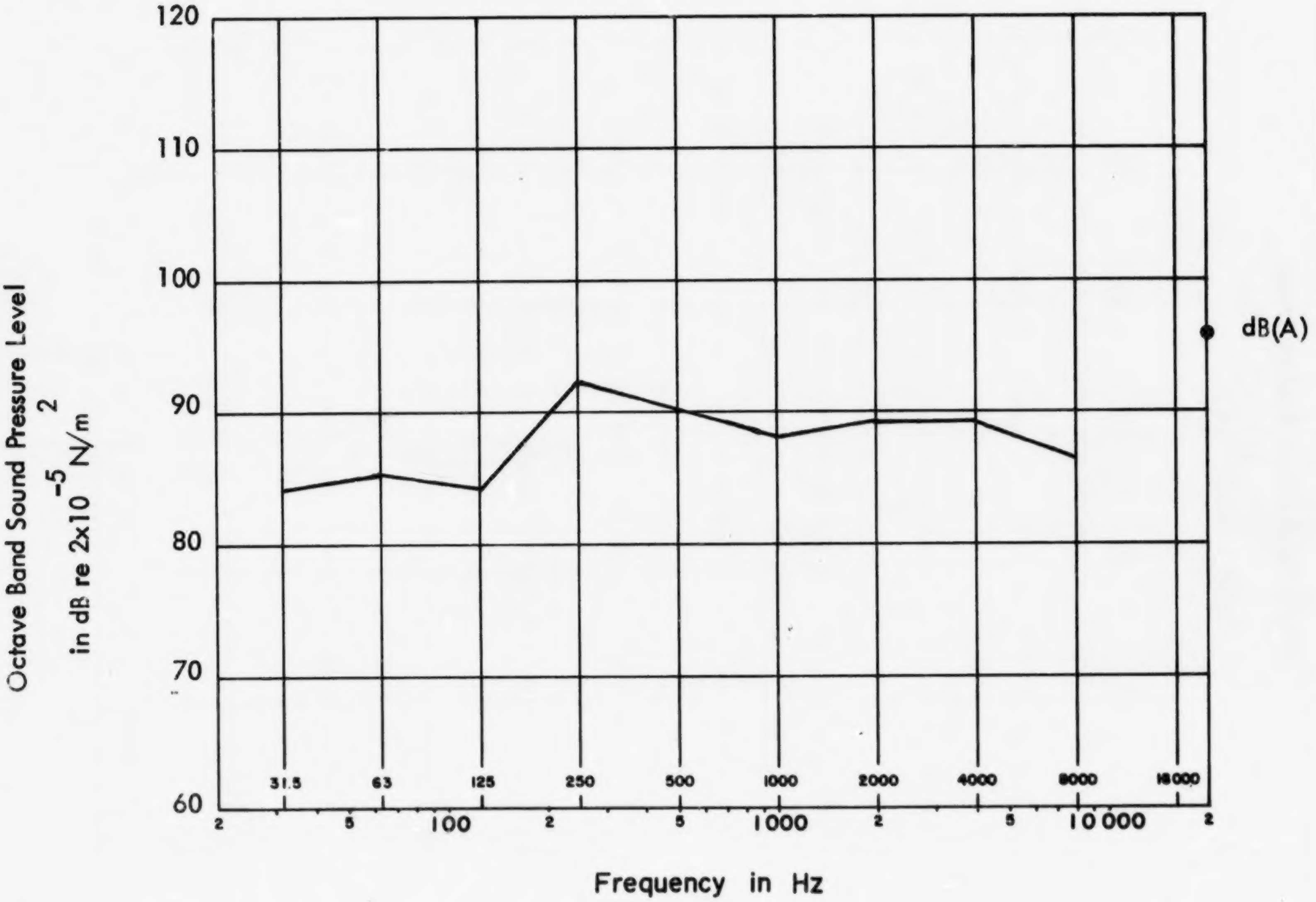


Figure 3.5.2-8. Octave Band Sound Pressure Levels of a Double Seamer Line in a Can Manufacturing Plant.

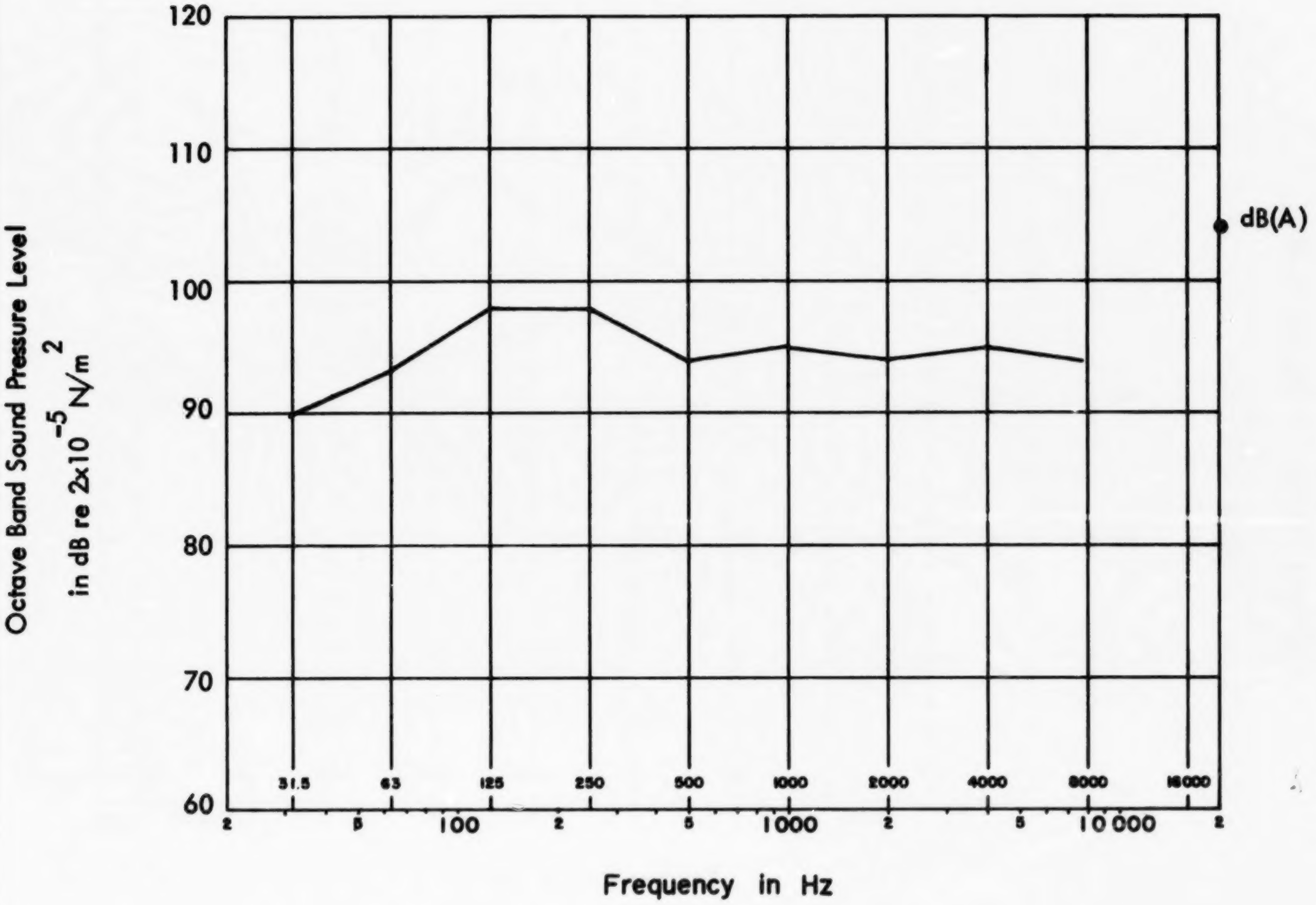


Figure 3.5.2-9. Octave Band Sound Pressure Levels of a Minster Ring Pull Press (Near Operator) in a Can Manufacturing Plant.

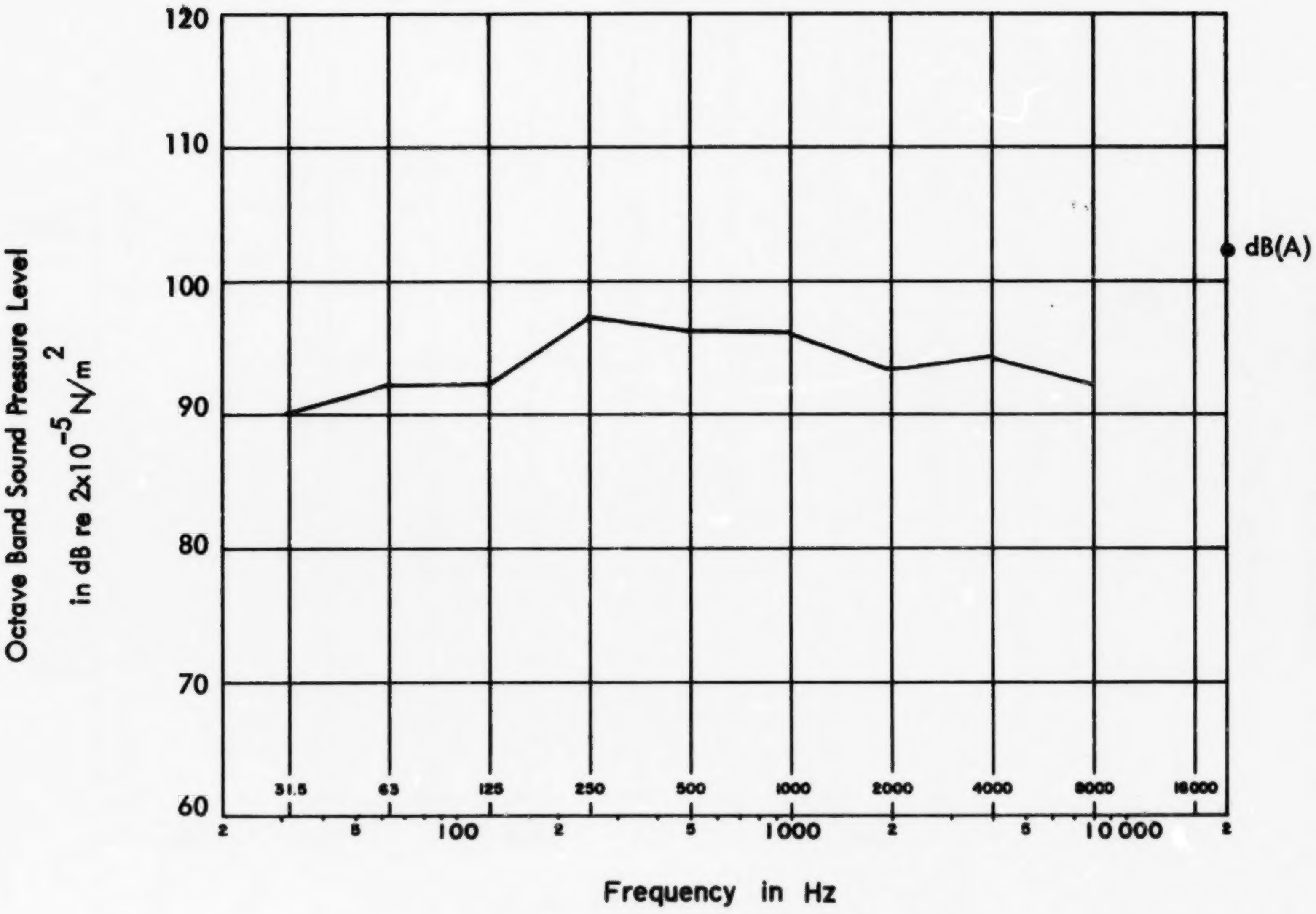


Figure 3.5.2-10. Octave Band Sound Pressure Levels of a Punch Press (720 Strokes/Minute) in a Can Manufacturing Plant.

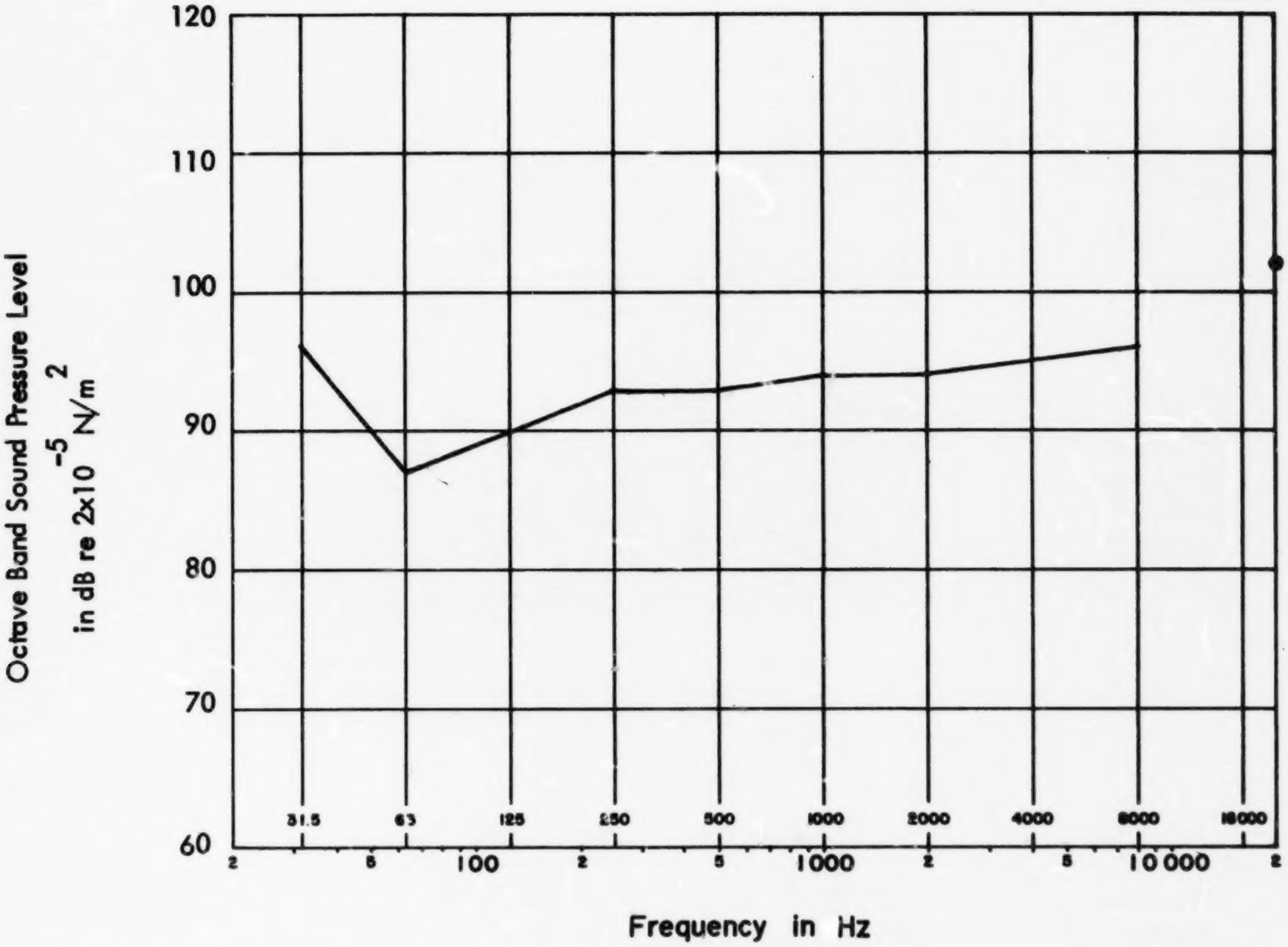
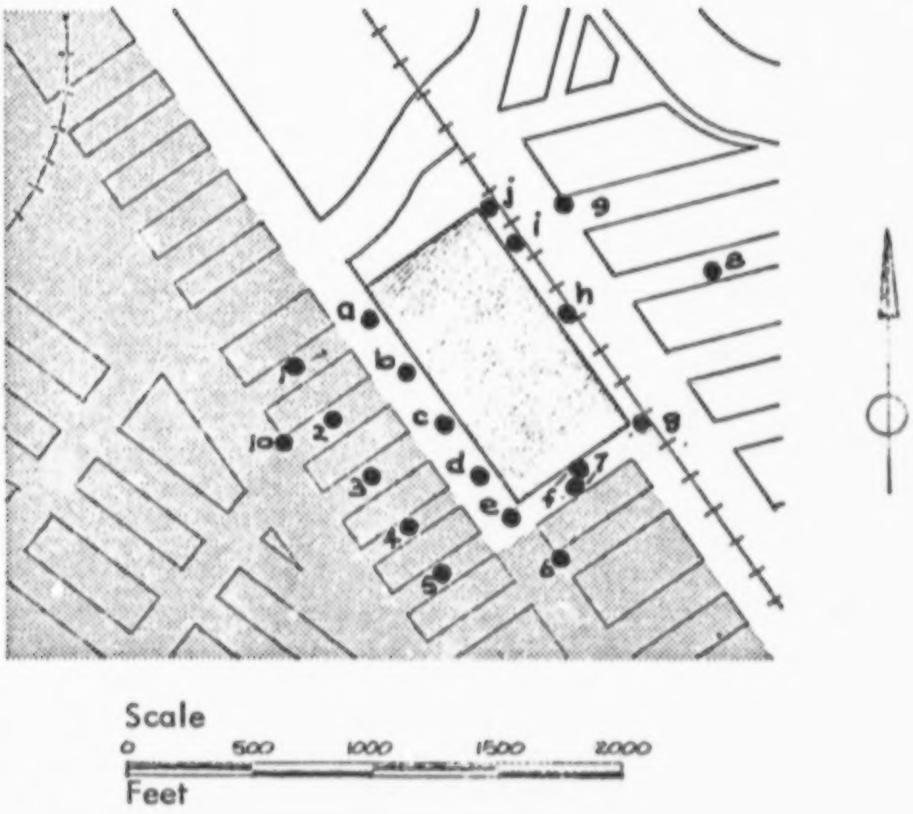


Figure 3.5.2-11. Octave Band Sound Pressure Levels of a Body Maker in a Can Manufacturing Plant.


a
b
c
d
e
f
g
h
i
j
1
2
3
4
5
6
7
8
9
10
Scale
0
500
1000
1500
2000
Feet

	Community Noise Levels in dB(A)									
	1	2	3	4	5	6	7	8	9	10
Weekend	55	49	53	51	50	50	57	56	51	58
Weekday	53	49	55	49	51	54	59	56	56	55
Weeknight	48	49	53	51	47	49	58	50	55	47

	Plant Property Line Noise Levels in dB(A)									
	a	b	c	d	e	f	g	h	i	j
Weekend	58	59	59	61	58	58	52	50	49	53
Weekday	60	65	64	65	60	60	56	52	57	63
Weeknight	53	63	63	61	58	62	53	43	53	66

Key

▩	Industrial Noise Source
░	Residential Area
┼┼┼┼┼	Railroad Track
═	Highway
●	Measurement Location

Figure 3.5.3-1. Can Manufacturing Plant Community

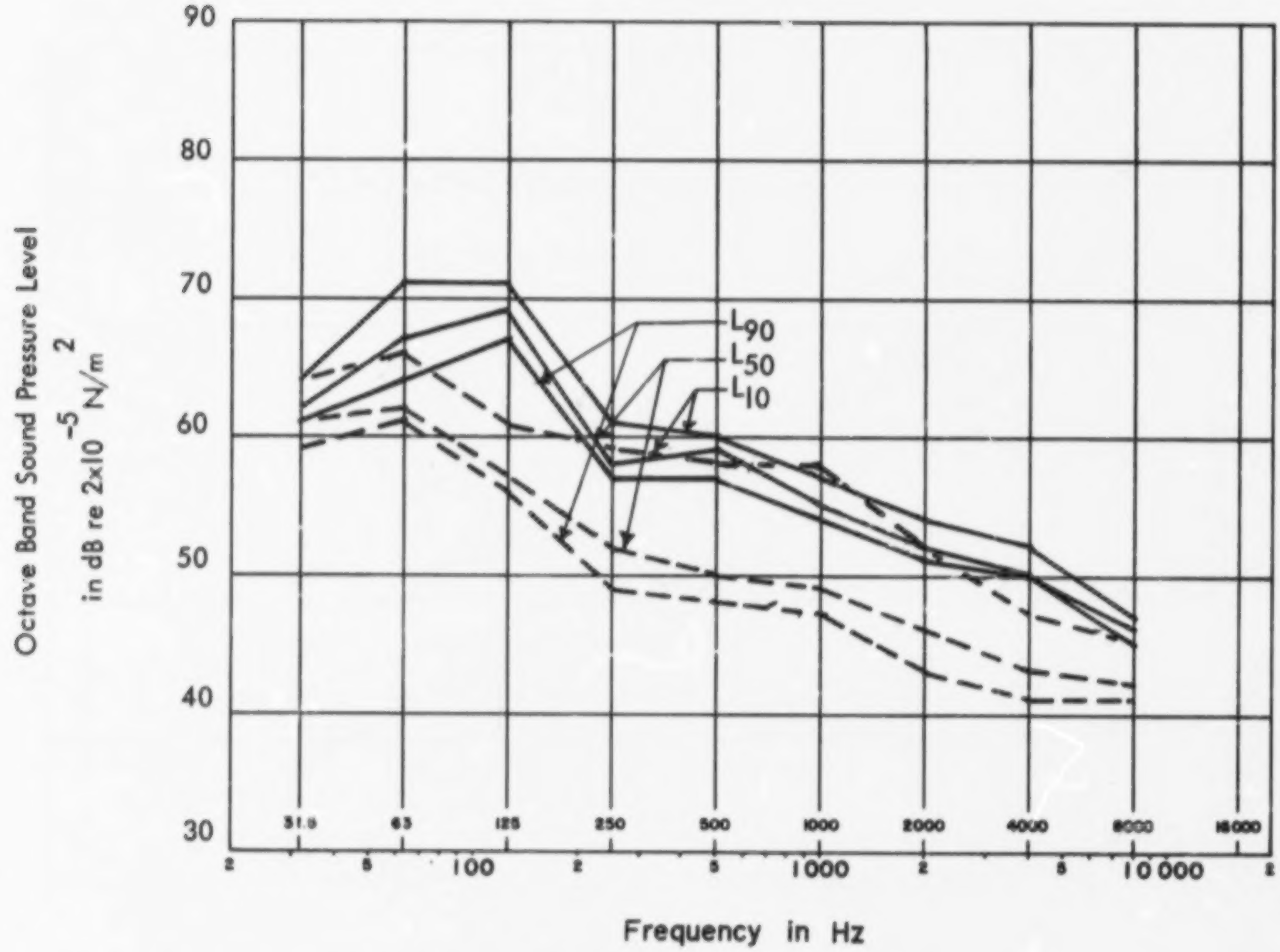


Figure 3.5.3-2. Can Manufacturing Plant Location I.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – Nighttime

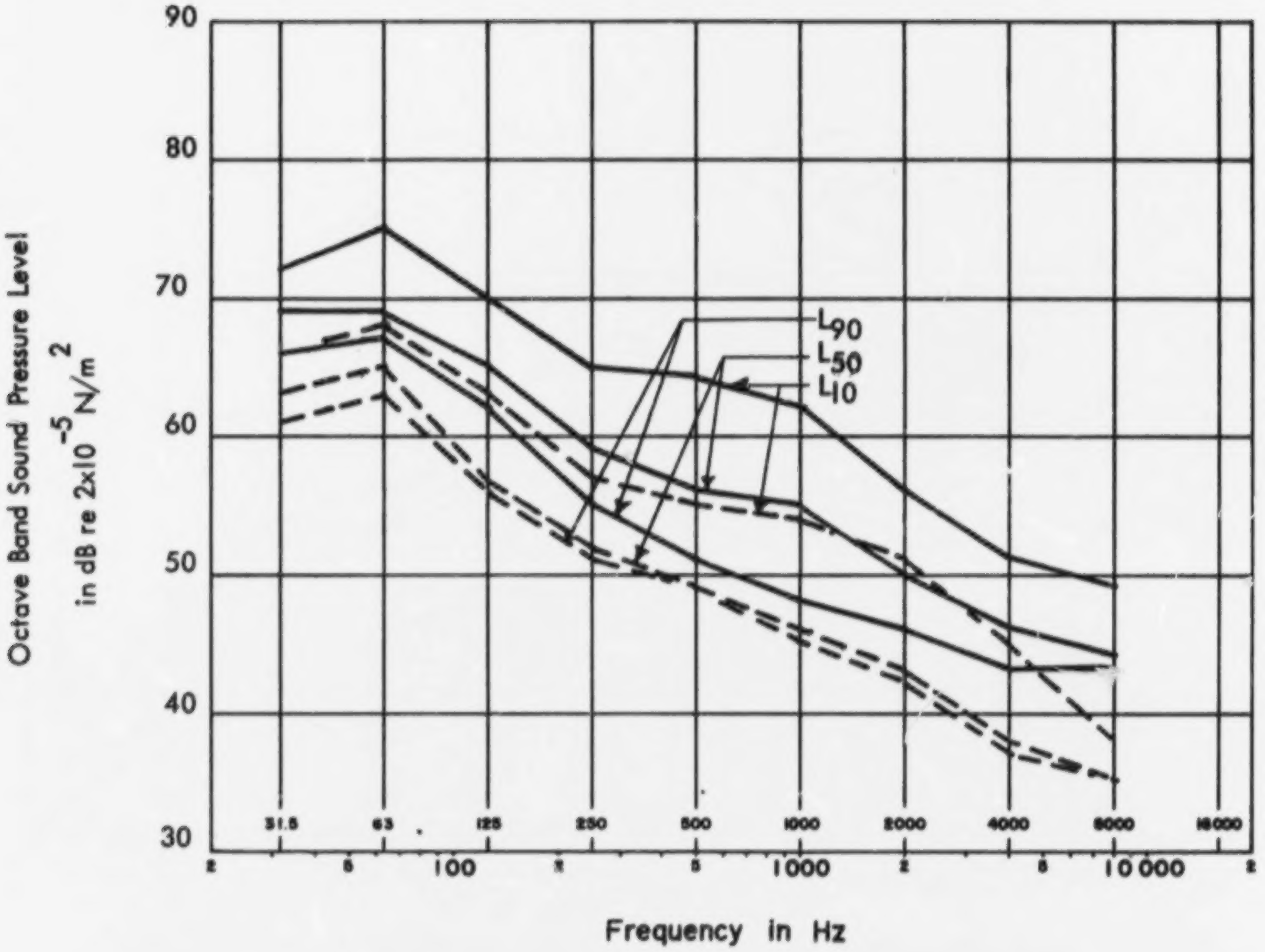


Figure 3.5.3-3. Can Manufacturing Plant Location 2.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

—— Daytime

– – – Nighttime

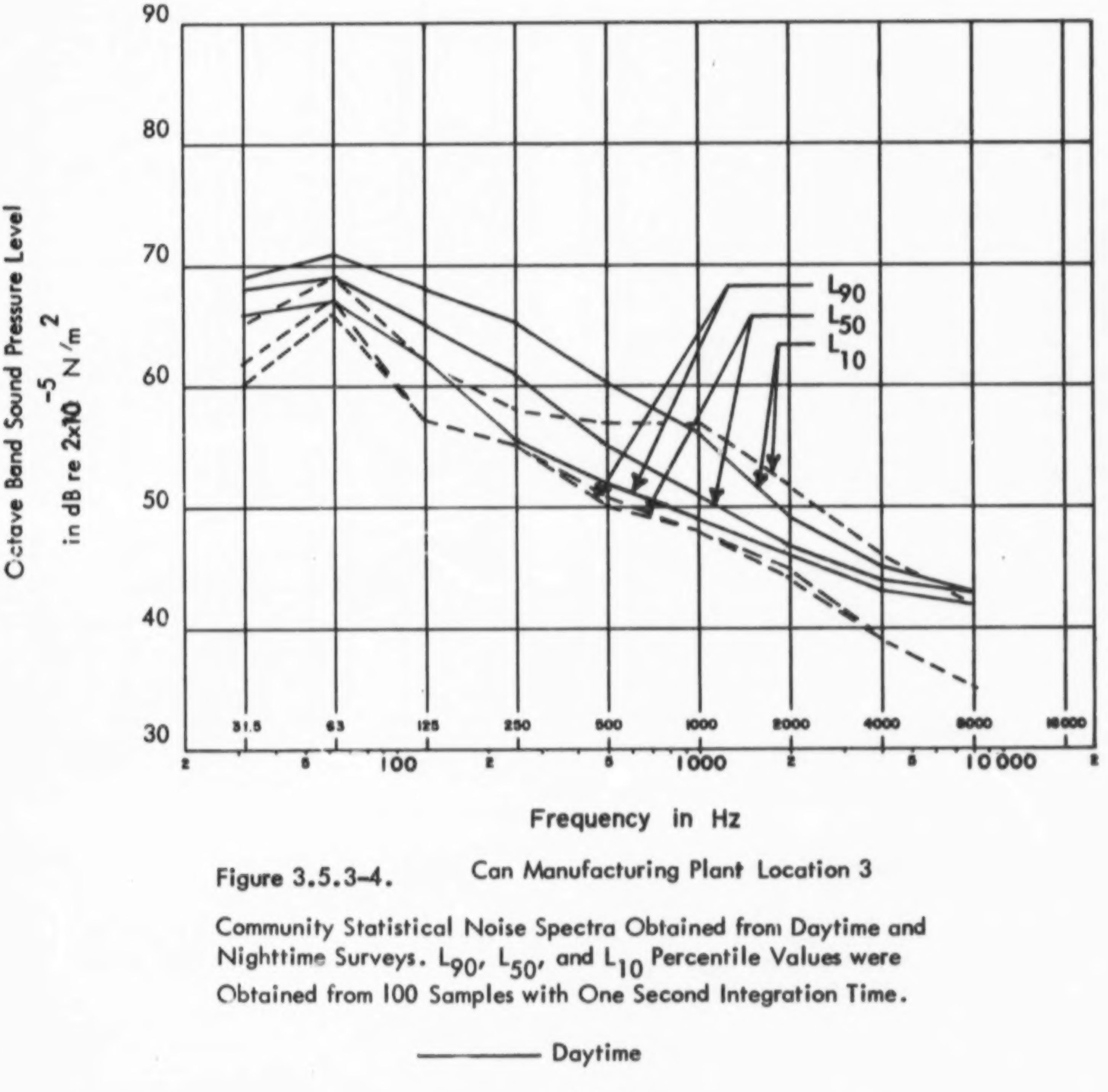


Figure 3.5.3-4. Can Manufacturing Plant Location 3

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – – Nighttime

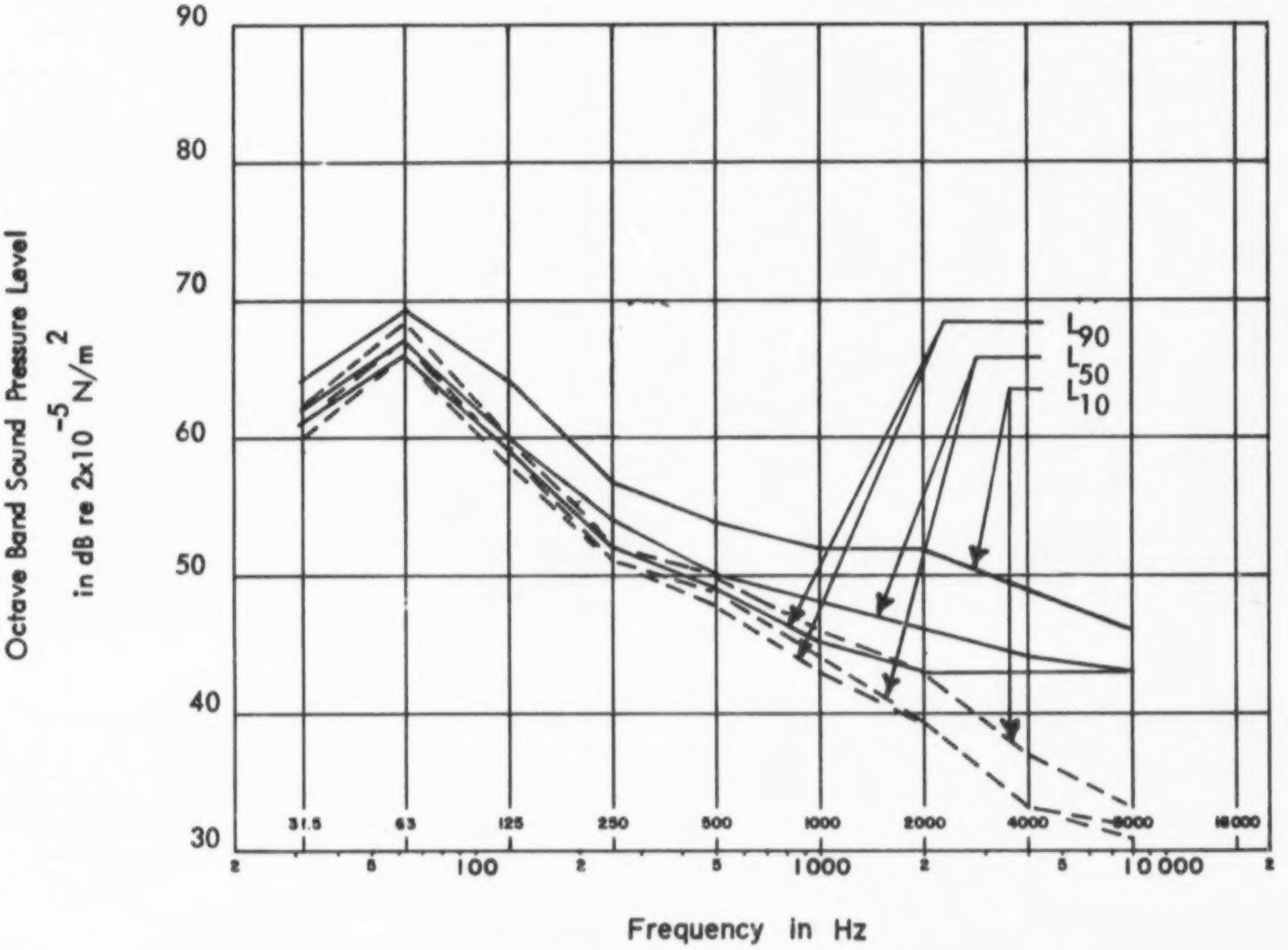


Figure 3.5.3-5. Can Manufacturing Plant Location 4

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——————— Daytime

– – – – – – Nighttime

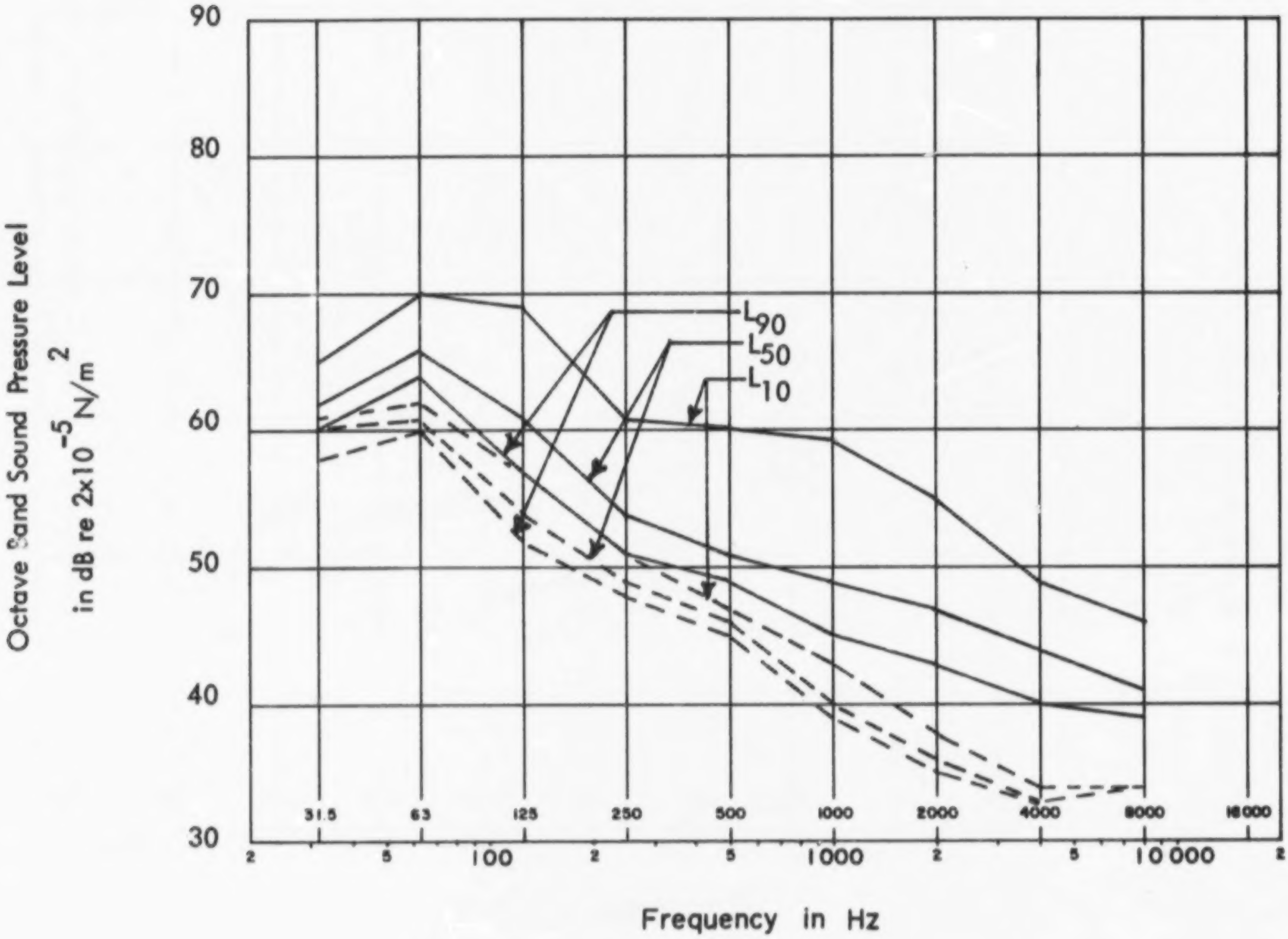


Figure 3.5.3-6. Can Manufacturing Plant Location 5

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——————— Daytime

– – – – – – Nighttime

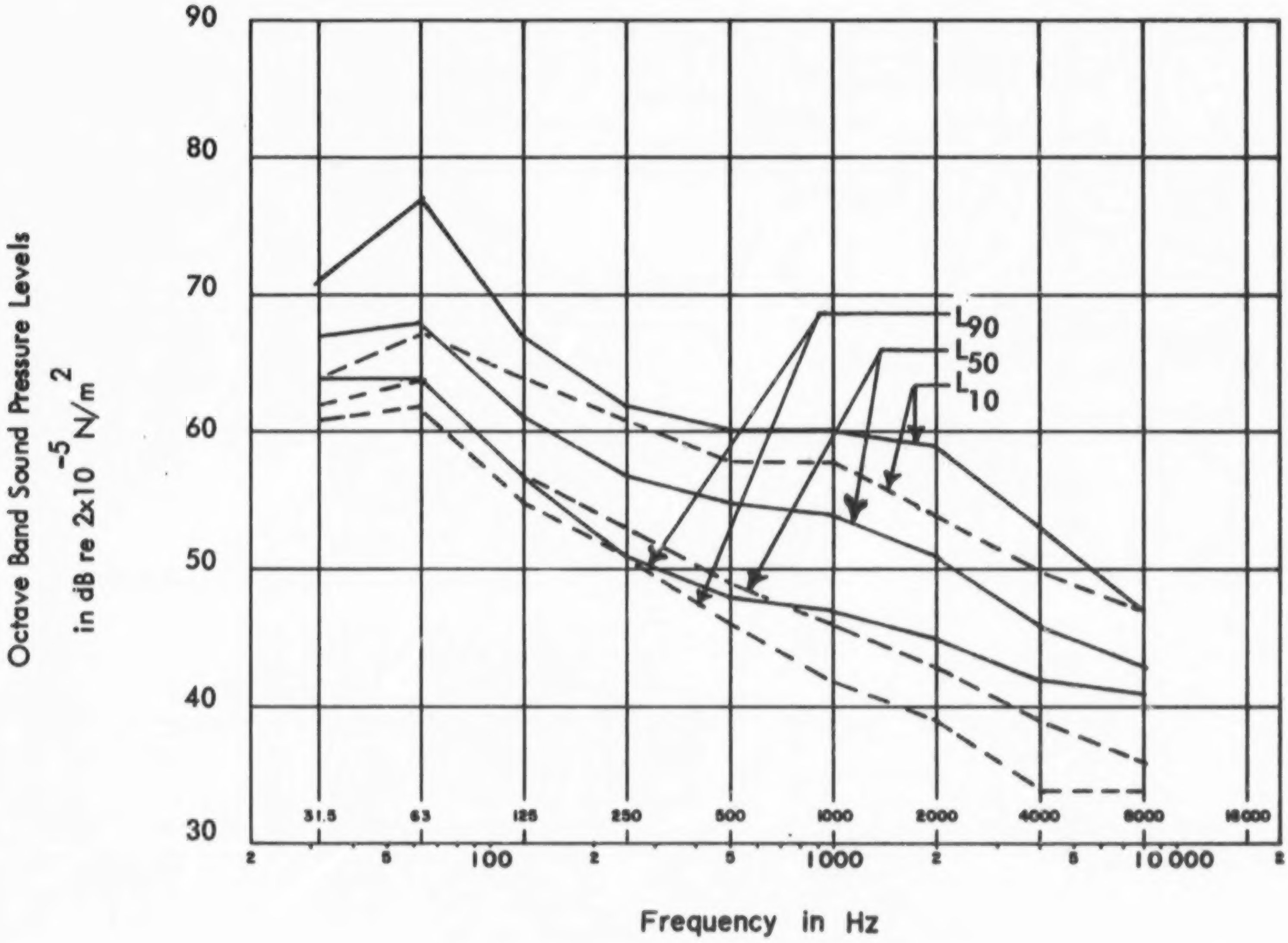


Figure 3.5.3-7. Can Manufacturing Plant Location 6

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

———— Daytime

– – – – – Nighttime

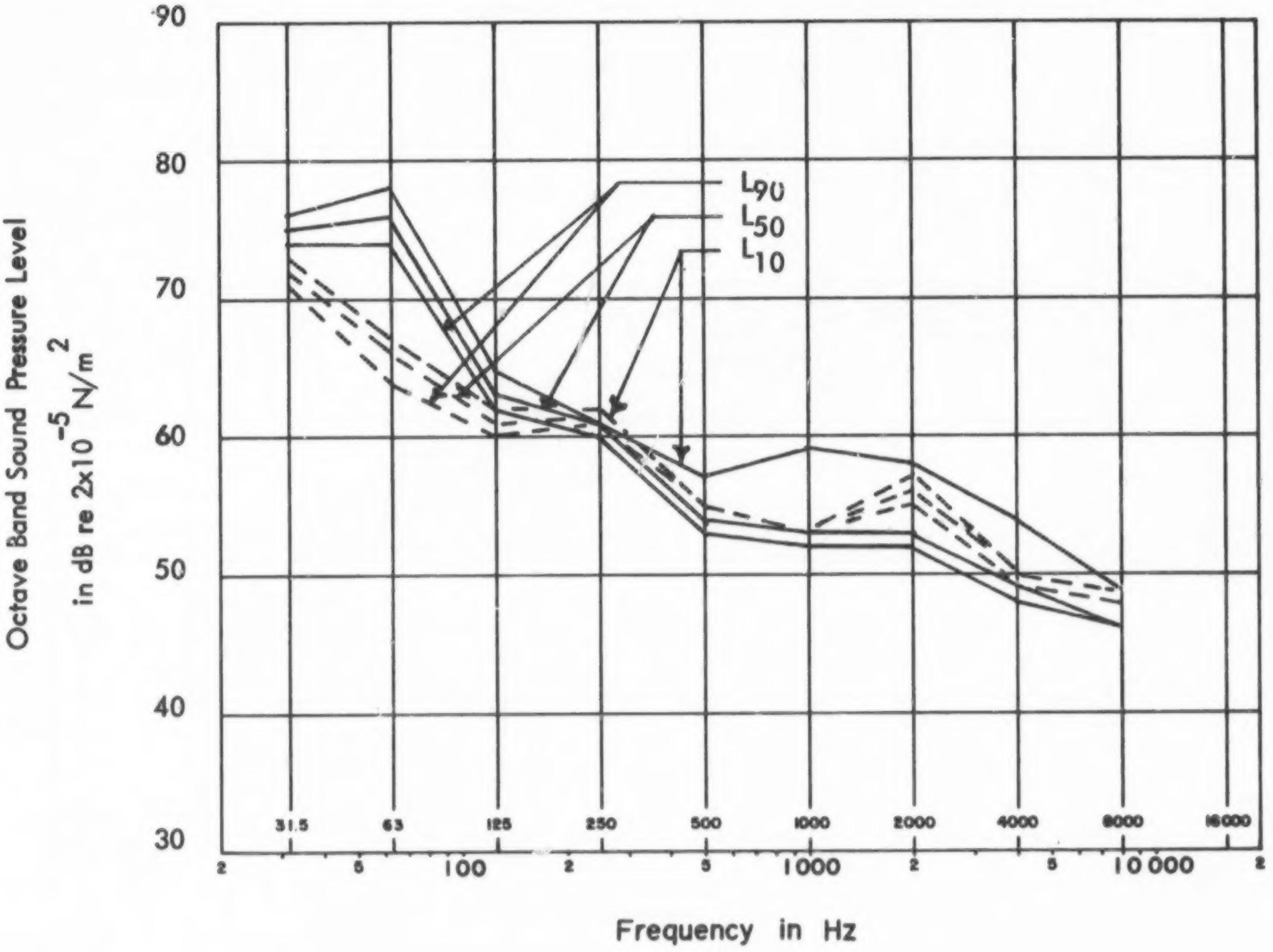


Figure 3.5.3-8. Can Manufacturing Plant Location 7

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentila Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

– – – – Nighttime

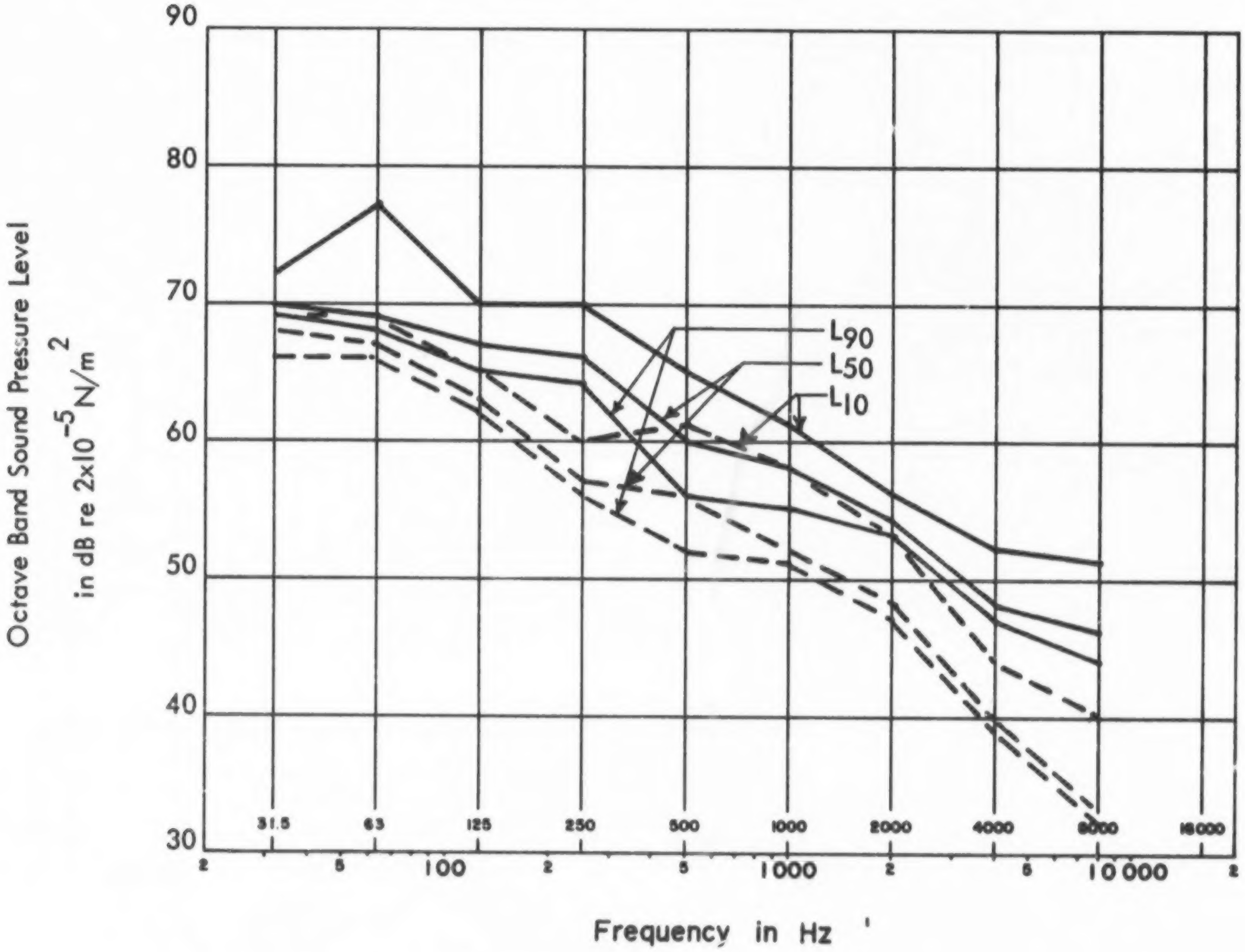


Figure 3.5.3-9. Can Manufacturing Plant Location 8.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

— — — Nighttime

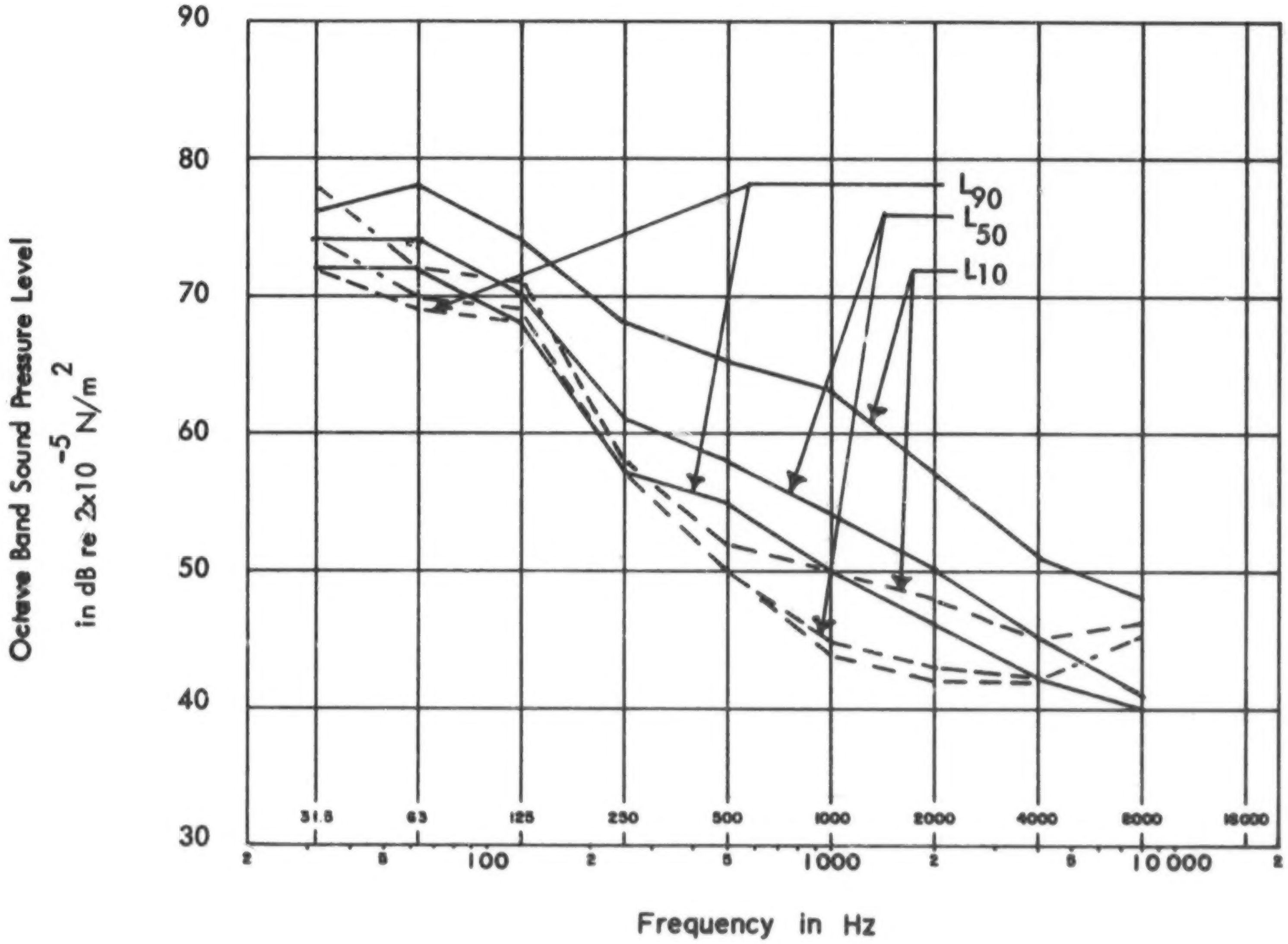


Figure 3.5.3-10. Can Manufacturing Plant Location 9

Community Statisical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples. With One Second Integration Time.

——— Daytime

– – – – – Nighttime

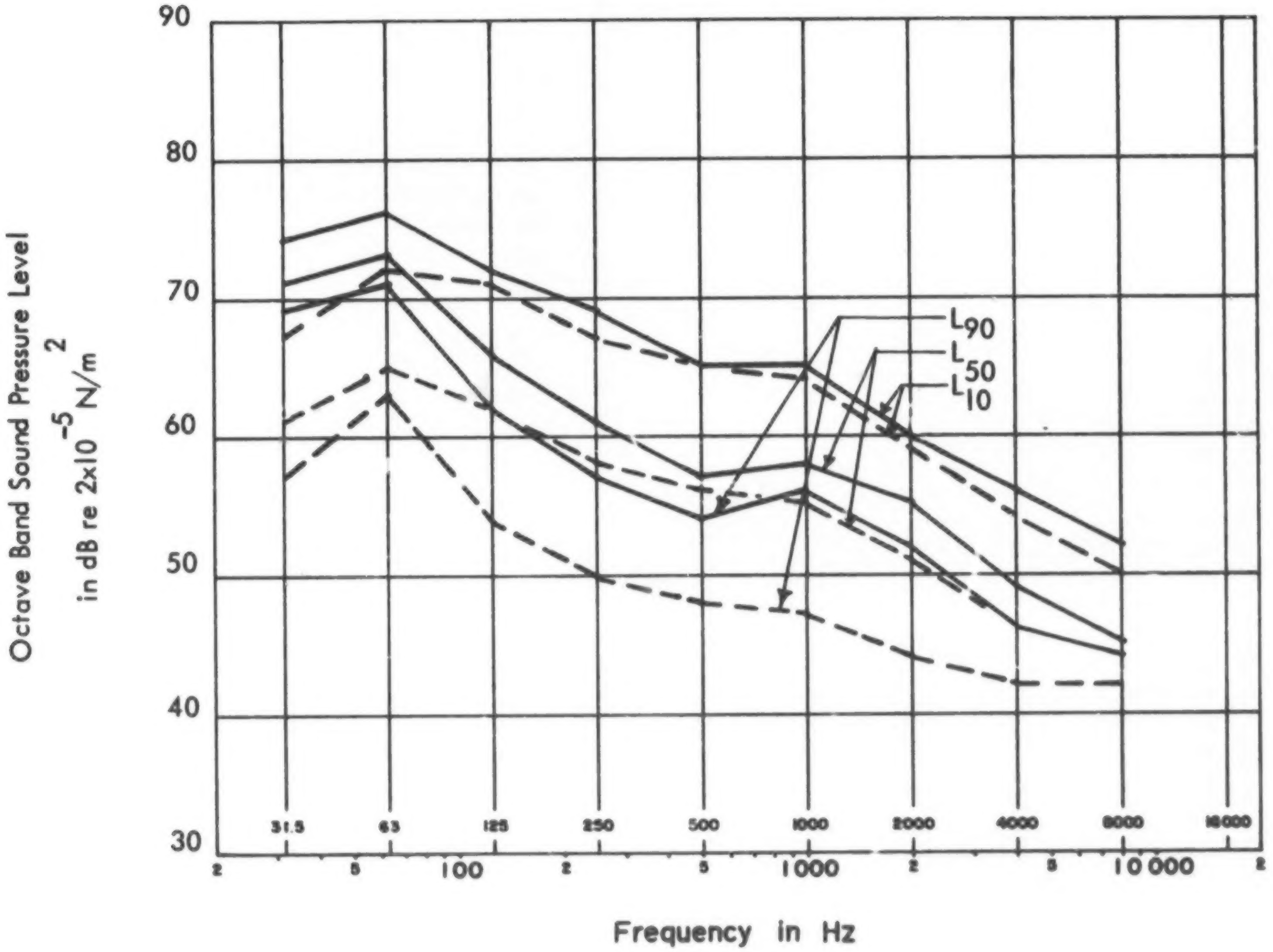


Figure 3.5.3-11. Can Manufacturing Plant Location 10.

Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90}, L_{50}, and L_{10} Percentile Values were Obtained from 100 Samples with One Second Integration Time.

——— Daytime

— — — Nighttime

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A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55
56
57
58
59 *
60
61 ****************
62 **********************
63 ******
64 **
65 *
66 **
67
68
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46
47
48 **************************
49 *******************
50 *****
51
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.5.3-12. Can Manufacturing Plant Location 1.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
55 *****
56 ******
57 ****
58 **
59 *****
60 ****
61 *****
62 **
63 **
64 ***
65 ***
66 ***
67 ***
68 *
69 *
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
45
46
47
48 ******
49 ************
50 *****
51 ***
52 **
53 ***
54 ***
55 **
56 *
57 **
58 *
59 *
60 **
61 **
62 *
63 *
64
65
66 *
67
68 *
69 *
70
```

Number of Occurrences
Nighttime

Figure 3.5.3-13. Can Manufacturing Plant Location 2.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
55
56 *******
57 ****
58 **********
59 ************
60 ********
61 *****
62 *
63 ***
64
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
50
51
52
53 *********
54 ****************************
55 ****
56 **
57
58 *
59 *
60 *
61
62 *
63
64 *
65 *
66
67 *
68
69
70
```

Number of Occurrences
Nighttime

Figure 3.5.3-14. Can Manufacturing Plant Location 3.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
45
46
47
48 *
49
50
51
52
53
54 *
55 *******
56 ***********
57 *****
58 ****
59 *****
60 ****
61 *****
62 *
63 **
64 ****
65
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re $2x10^{-5}$ N/m^2

```
50 *******************************
51 **********
52 ****
53 *
54 *
55
56
57
58 *
59
60
61
62
63
64
65 *
66 *
67
68
69
70
```

Number of Occurrences
Nighttime

Figure 3.5.3-15. Can Manufacturing Plant Location 4.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55 *********
56 *****
57 *********
58 ****
59 ****
60 *****
61 **
62 *
63
64 ***
65 **
66
67 *
68 **
69 *
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re x10^{-5} N/m^2

```
45
46 *
47 *******************
48 *********************
49 ******
50 **
51 *
52
53
54
55
```

Number of Occurrences
Nighttime

Figure 3.5.3-16. Can Manufacturing Plant Location 5.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
50
51
52
53 **
54
55 **
56 ***
57 *****
58 ****
59 *******
60 ***
61 ***
62 *
63 ******
64 **
65 ***
66
67 **
68 **
69 *
70 *
71 ***
72
73
74
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46
47
48
49 *********
50 ***
51 ********
52 ****
53 ***
54 ****
55 **
56 *
57 **
58
59 **
60 *
61 **
62 ****
63 **
64
65 **
66
67 *
68
69
70
```

Number of Occurrences
Nighttime

Figure 3.5.3-17. Can Manufacturing Plant Location 6.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56
57 *
58
59 **
60 **************
61 ***************
62 *********
63 ***
64 *
65 **
66 **
67 *
68
69
70
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56
57 *****
58 **********************************
59 *****
60
61 **
62 *
63 *
64
65
```

Number of Occurrences
Nighttime

Figure 3.5.3-18. Can Manufacturing Plant Location 7.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

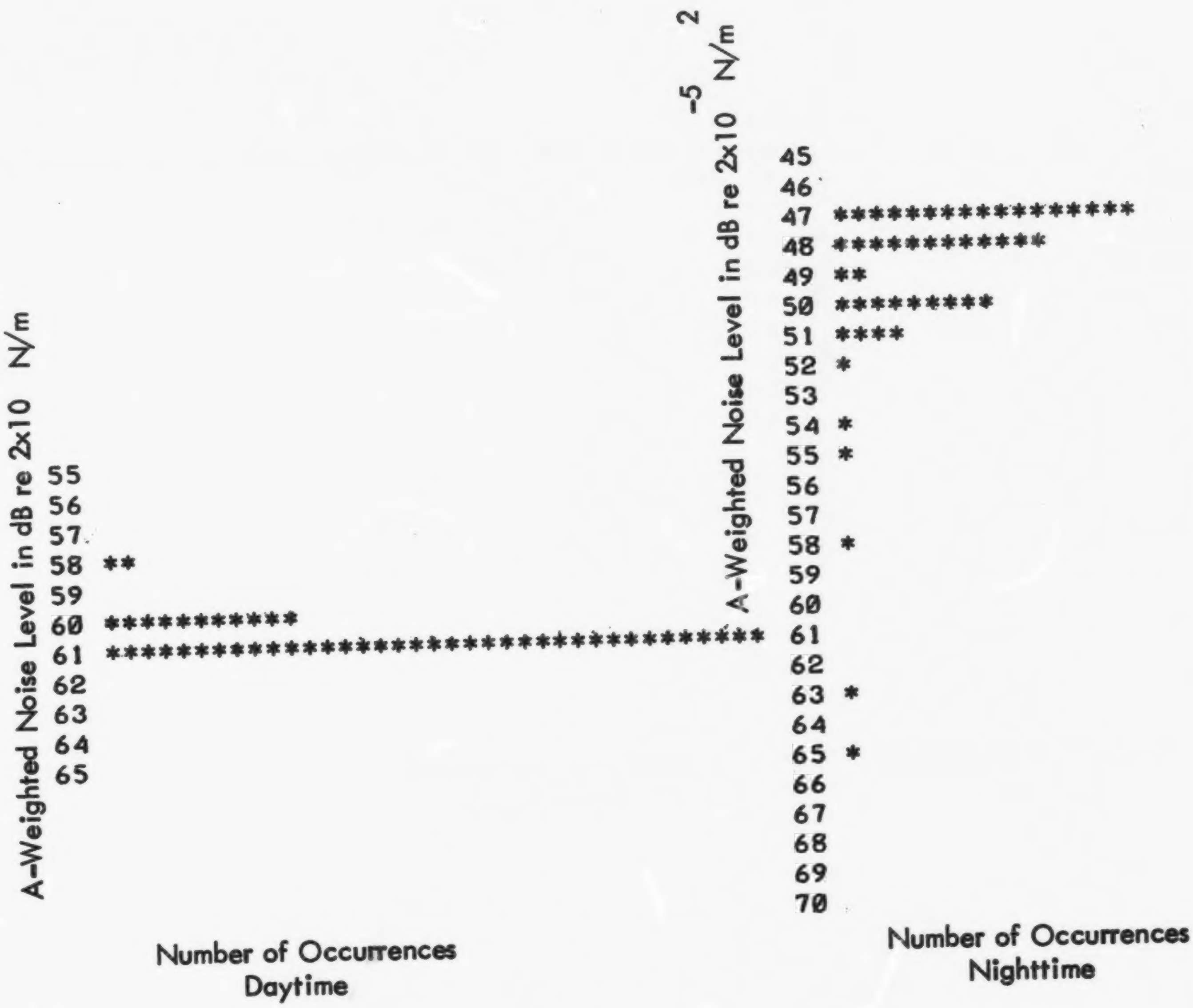

Figure 3.5.3-19. Can Manufacturing Plant Location 8.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55 ******
56 **************
57 **
58 ****
59 *****
60 *****
61
62 ***
63 **
64 *
65
66
67 *
68 *
69 ***
70
71
72 **
73
74 *
75
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2x10^{-5} N/m^2

```
55
56 ***********************************************
57 ***
58
59
60
61
62
63
64
65
```

Number of Occurrences
Nighttime

Figure 3.5.3-20. Can Manufacturing Plant Location 9.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
55
56
57
58
59 **
60 ****
61 ***************
62 *****
63 **
64 **
65 *
66 ******
67 ***
68 **
69
70 *
71 ****
72 *
73
74 *
75 *
76
77
78
79
80
```

Number of Occurrences
Daytime

A-Weighted Noise Level in dB re 2×10^{-5} N/m^2

```
45
46 *******
47 *************
48 *******
49 ****
50 **
51 **
52 ****
53 *
54 **
55 **
56 ***
57 *
58 **
59
60
```

Number of Occurrences
Nighttime

Figure 3.5.3-21. Can Manufacturing Plant Location 10.

Noise Level (A-Weighted) Histogram 50 Samples Four Second Integration.

Table 3.5.3-1 – Intrusive (L_{10}) Noise Level (A-Weighted) Observed at Can Manufacturing Plant Community Locations During Day, Evening, and Nighttime Sampling Periods

Location	Noise Level dB(A)		
	Day	Evening	Night
1	54		49
	57		52
	58		53
	63		61
2	54		60
	57		53
	66		63
	48		58
3	60		60
	57		53
	62		54
	62		54
4	54		53
	53		51
	63		52
	58		52
5	56		49
	63		50
	63		57
	65		
6	65		62
	66		58
	67		65
	70		53
7	60		59
	64		57
	63		61
	66		61
8	55	62	53
	60		49
	61		53
	67		
9	67	64	56
	64		56
	66		58
	66		
10	67		56
	67		56
	69		65
	66		68

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4. IMPACT OF PLANT NOISE SOURCES

4.1 On the Work Environment

The impact of the major noise sources of a typical glass manufacturing plant combines with the impact due to heat to yield a rather uncomfortable work environment. The major sources of noise are the I.S. machines which are similar to blow molding machines. Noise levels A-weighted at operator positions at these machines range from 99 to 103 dB. Besides high damage risk to hearing, Preferred Frequency Speech Interference Levels (PSIL) are sufficiently high so that conversations between foremen and workers are exceedingly difficult.

At stations where the glassware is inspected by employees, the noise levels A-weighted range from 87 to 96 dB. These excessive noise levels are known to provide high damage risk to hearing and reduce the effectiveness of the inspection process.

The impact of the major noise sources on the work environment at an oil refinery is minimal. The furnaces, compressors, and cracking units are operated remotely. During periodic inspections, personnel are required to wear ear protection devices in high noise areas. These devices take the form of ear plugs or ear muffs and do not hamper the employee's work in any manner.

The impact of the major noise sources on the work environment at a power plant is minimal. Furnaces, gas turbine and steam turbo-generators, switching stations, and transformers are operated remotely. During periodic inspections, personnel are required to wear ear protection devices in high noise areas. These devices take the form of ear plugs, ear muffs, and hard hat-ear muffs which do not hamper employee's work in any manner.

Noise source impact upon the work environment at the typical automotive assembly plant varies from "minimal" to "considerable." The noise levels A-weighted at many locations within the plant have been reduced to below 90 dB. At locations such as the rough grind booth where this reduction could not be accomplished, ear protective devices in the form of ear muffs are required. The ear muffs in combination with protective clothing cause discomfort, particularly during the summer months.

At other locations throughout the plant, e.g., metal finishing, manual air blow-off, pneumatic tool assembly, etc., the

Preferred Frequency Speech Interference Level is quite high, making communication between foremen and workers quite difficult.

The impact of noise upon the work environment of the can manufacturing plant visited is very serious. The plant employs approximately 1000 hourly workers on a three-shift basis. A significant number of hearing compensation legal actions prompted management to institute a mandatory hearing conservation program in August of 1971. The company provides molded ear plugs to each plant employee with one or more years of service. Shorter term employees or those not yet fitted with the molded ear plugs are required to wear ear muffs. During a recent inspection, it was observed that approximately 80 percent of the employees were using the ear protection devices.

The metal cutting and forming machines are very noisy. Presses used for installation of "ring pulls" produce a noise level A-weighted of 104 dB. Air compressor units are located in the middle of the production area and are not separated from the work environment by any acoustical barrier. The noise level A-weighted at this location is 99 dB. At an employee "rest" area the noise level A-weighted is 98 dB. Communication throughout the plant is difficult due to the high Speech Interference Levels.

4.2 On the Community Environment

4.2.1 Magnitude of the Impact

Statistical Abstracts of the United States published by the Bureau of Census for the year 1967, reported that the total number of industrial establishments in the United States was 311,000, employing approximately 14,356,000 workers in production. It is well known that many types of industries make noise, and that some members of the nearby community object to this noise while other neighbors do not. This case study indicates that the community noise is often due to the combined effects of surface transportation, construction activity, and the plant. Even for the case where plant noise is the only source or the predominant source, the number of persons subject to the noise is small.

For a plant located in a suburban area, the number of adjacent neighbors may be no more than 100 to 300 persons. The urban plant may have a greater number of neighbors, but the noise of the plant is often masked by highways, heavily travelled streets, construction, or airports. If we conservatively estimate that the average number of persons subjected to plant noise is 500 persons per plant and make the obviously incorrect assumption that each of the 311,000 industrial plants in the United States is the predominant community noise source, then about 16,000,000 persons are affected, which is less than 10 percent of the population of the United States.

4.2.2 Behavioral Response

A review of the data resulting from the case studies shows that although interior plant noise levels due to individual machines, equipment, or processes are exceedingly high, the impact of the plants on the communities as indicated by the community complaint histories, is not as high as might normally be anticipated. High plant noise levels of some of the plants of this study are reduced by plant building construction or the distance of the plant to the community. Often the plant noise combines with the other sources mentioned above to create the total community climate. It should be noted that each of the five plants in this study is located in areas where the residual noise levels are relatively high. When the community noise levels (A-weighted) are compared with levels shown in the Wyle Contractors' Report, NTID 300.3, the communities adjacent to each plant may be categorized as follows:

- Glass Manufacturing Plant - Quiet suburban residential to normal suburban residential.
- Oil Refinery - Urban residential to noisy urban residential.
- Power Plant - Urban residential to noisy urban residential.
- Automobile Assembly Plant - Urban residential.
- Can Manufacturing Plant - Urban residential to very noisy urban residential.

It is evident that the specific plants of this case study have no great impact upon the communities. One exception is the glass manufacturing plant, where the noise levels exceeded the nearby community levels by nine to 15 dB(A). This higher noise level was also evident at night. One family is exceedingly disturbed. Other neighbors, no more than 25 adults, are also disturbed but to a lesser extent. The tonal qualities of the gas turbine noise reaching the power plant community during periods of high power demands generated sporadic complaints.

Complaints as an indicator of community impact must be used with caution, as it is known that industrial neighbors may not object to plant noise, even at fairly high levels, if:

(a) It is continuous,

(b) It does not interfere with speech communication,

(c) It does not include pure tones or impacts,

(d) It does not vary rapidly,

(e) It does not interfere with getting to sleep, and

(f) It does not contain fear-producing elements.

Counterbalancing the above effects, single individuals of families may be annoyed by an industrial noise that does not annoy other plant neighbors. This often may be traced to unusual exposure conditions, or to interpersonal situations involving plant management.

In the next section a process will be described in some detail regarding the accommodation which exists between a plant management and the neighboring community, which begins during the process of seeking an industrial site within the community and continues throughout the plant's existence in the community.

4.2.3 Plant-Community Accommodations

The management of any company, large or small, when planning to build a plant or to lease a building for the plant goes through a selection process. This process may, at a minimum, consist of the search for an empty building for purchase or rent. For a major industry, the process involves many weeks, and possibly many months of research and study. Discussions with municipal officials, real estate experts, and possibly security, transportation, and communications experts are required. The company recognizes that it may not be wanted in a community if it will emit excessive amounts of particulates, unpleasant odors, or loud and unusual noises.

To assure acceptance or accommodation, company management examines proposed sites for nearby existing industries that have already been accepted. Also investigated is the level of control exercised by municipalities and the state government over these emissions. This is a first step in a self-limiting process. Even the small, one-lathe industries are not likely to locate any closer to residential neighbors than is absolutely necessary.

During the company's site location studies, it will have to consider the general requirements of each municipality in which land and facilities are available, so that by the time it starts to discuss its preliminary plans with town officials, the company can hope to accomplish the approval process in a reasonable time and begin to build. To accomplish this, it must first prepare a preliminary plant site layout, a proposed set of plans and elevations, and a set of general specifications involving water, sewerage, and traffic requirements which might be added to the community due to the location of the plant.

Many companies prepare handsome renderings of the building and detailed presentation brochures in order to present their case to the municipal officials. Often, an initial presentation is made unofficially to the mayor and the town council before formal submissions are made to the zoning board. Usually the mayor and council can adjudge the financial advantages and must then examine the possibility of additional costs to the municipality and the possibility that the industry might not really be as desirable as the presentation they have made would lead the viewer to believe. The result is that often there is considerable negotiating before the formal presentation is made. These negotiations may include the addition of company installed roads, sewers, parks, waste-water treatment, and special noise abatement facilities. Faced with these requirements, the company management might decide that it is too costly to meet the municipality's goals, and therefore, may move elsewhere.

The company management might also anticipate that because of an apparent negative citizen feeling in the town, they would be much wiser to locate in a more welcoming community.

After approval by the zoning board, and this may take as long as six months after first discussions with the mayor and council, the notification of approval goes to the mayor and council for formal approval by that body. Again, it is usual for public hearings to be held, although on occasion executive sessions of the zoning board are followed by executive sessions of the council. This practice is normally frowned upon by the general public and the press. In the case where public hearings are held by the council, if the public felt that the zoning board had not fully considered their needs and requests, the public may show up with an attorney and several experts at the council meetings. The industry on its part may be prepared to make a full-scale presentation and a rebuttal. Finally, the council meets in either public or private session and decides the question. Even then, the public may obtain an injunction against the construction of the plant, or, by its show of massive rejection of the company, persuade the management that it would be wise to seek a site elsewhere.

Even where approval is obtained, the state labor department may have to approve the plans. A building inspector checks the construction as it progresses. At any time up to the time a certificate of occupancy is issued by the building inspector, the municipal officials may review the situation. The town council, on the basis that the company has not made a full disclosure or the actual construction differs in some major ways from the plans, rendering, or brochure, may require extensive changes to the plant. In any case, the municipality has tremendous leverage. The municipal officials are not just local business men. They usually include experienced real estate and insurance men, engineers, educators, and people from all walks of life who have a keen dedication. Their demands may often be politically inspired, but in general they have a knowledge of the needs of their fellow citizens and seek to meet these needs.

Even with the issuance of a certificate of occupancy, the company's liability for further noise abatement efforts is not over. Often the municipal health officer and the police still have powers to cite management responsible for producing loud or unusual noises. The local statutes frequently give wide powers to the municipal officials and police in dealing with these violators.

To understand this accommodation process better, let us look at a typical industrial/residential township located in a suburban/rural region of a northeastern state. This township has a comprehensive zoning regulation, including performance code sections for air and noise emissions. Not every zoning regulation has a noise control performance code, but during the past 15 years, the attention to noise on the part of board members and private citizens has been growing. The noise portion of the regulations includes a table of sound levels which shall not be exceeded at the property line of the plant. This performance zoning regulation was developed by the township's planning consultant in close cooperation with the town council and zoning board. The objective was to set forth some criteria by which new industries could judge the pollution control needs of their proposed plants. The regulation also gives the township officials the yardstick by which to assess the proposals illustrated by the preliminary drawings and specifications discussed previously. The zoning regulation also serves to guide existing industries who may become nonconforming due to alterations to their existing plants.

During the past 10 years, several industries in the township have modified their plants in a manner that exposes their neighbors to noise levels which are believed excessive. Several complaints have been made to township officials, who initiated inspections by a building inspector or health officer. In each ase, noise levels were measured at the plant line and in the community. In most cases, the industries involved were sensitive to their neighbors' problems as soon as they found that there clearly was an audible noise attributable to their operation. The speed with which they accomplished remediation varied in each case. Where speedy remedies were not available to the industry, operational constraints were used to minimize the noise exposure in the community. The township requested that company officials appear before the town council and report on their progress at suitable intervals. Citizens attending these meetings could always be counted on to express their views if they believed that the situation had not been remedied.

4.2.4 Community Noise Equivalent Level

It is difficult to assess the impact of plant noise on the community by simply viewing the A-weighted ambient noise levels at various locations in the community during the work day, work night, or the weekend (see Figures 1-1 through 1-5). To better understand the effects of the noise and to obtain some qualitative measure of these effect, various rating systems have been devised. Two rating systems most commonly used today are the Composite Noise Rating (CNR) and the Noise Exposure Forecast (NEF). Both forms require complex computation using the perceived noise level, a quantity calculated by a procedure developed to assess the noisiness of an aircraft sound. Our desire was to assess the community noise using the data which we had available, that is A-weighted noise levels, both ambient (L_{90}) and intrusive (L_{10}).

Recently an additional rating system has been introduced which utilized intrusive (L_{10}) A-weighting noise levels rather than the more complex perceived noise levels. This system developed by Wyle Laboratories and reported in their Contractors' Report to the Environmental Protection Agency NTID 300.3 is the Community Noise Equivalent Level (CNEL).

To compute the community noise equivalent level, the community noise recorded on magnetic tape was statistically analyzed to determine the intrusive (L_{10}) A-weighted noise levels. These noise levels were tabulated for each location for day, evening, and nighttime periods. These data are weighted and energy averaged in accordance with the formula equation 1.

$$CNEL = 10\ Log\ \left(\frac{1}{m+n+l}\right) \quad \sum_{i=1}^{m} Antilog\ (DL_{10}/10)_i$$

$$+\ 3 \sum_{i=1}^{n} Antilog\ (EL_{10}/10)_i + 10 \sum_{i=1}^{l} Antilog\ (NL_{10}/10)_i \qquad (1)$$

where m, n, l are the number of intrusive noise level values for day, evening, and nighttime sampling periods, respectively, DL_{10}, EL_{10}, NL_{10} are intrusive noise levels (A-weighted for day, evening, and nighttime sampling periods, respectively.

The CNEL values thus computed from A-weighted noise levels at locations in the communities adjacent to the plant are summarized in Table 4.2.4-1. The CNEL value shown at the bottom of each column is obtained by energy averaging the CNEL value for each measurement location. The data obtained from Location 1 at the oil refinery community was not used since it was determined that the principal noise source at that location was a chemical plant and not the refinery.

These community noise equivalent levels must be adjusted for the season, time of day, background noise level, previous exposure and community attitude, and pure tone or impluse. Table 4.4.4-2 summarizes types of corrections and provides description and the amount of correction to be added.

Table 4.2.4-1 - Community Noise Equivalent Levels for Community Locations Adjacent to Typical Industrial Plants

	Community Noise Equivalent Level in dB(A)				
Location[a]	Glass Manufacturing	Oil Refinery	Power Plant	Automobile Assembly	Can Manufacturing
1	68.0	-	65.5	62.6	64.0
2	69.4	65.3	68.3	60.9	67.3
3	55.1	61.4	66.2	65.1	64.3
4	51.6	67.4	69.6	62.3	60.7
5	54.0	62.7	71.8	65.1	63.1
6	59.6	70.9	73.5	66.2	69.8
7	52.4	69.1	68.2	60.5	67.7
8	51.3	59.0	69.0	66.6	63.3
9	54.8	66.7	-	62.8	66.6
10	61.1	-	-	-	71.9
11	60.3	-	-	-	-
12	62.2	-	-	-	-
13	53.8	-	-	-	-
Energy Average	62.2	66.8	69.8	64.1	67.2

(a) See Figures I-I through I-5 for Measurement Locations

Table 4.2.4-2 - Corrections to be Added to the Measured Community Noise Equivalent Level (CNEL) to Obtain Normalized CNEL (from Wyle)

Type of Correction	Description	Amount of Correction to be Added to Measured CNEL in dB(A)
Seasonal Correction	Summer (Year-around operations)	0
	Winter only (or windows always closed)	-5
Time of Day	Daytime	0
	Evening	+5
	Night time	+10
Correction for Background Noise	Very quiet suburban or rural community (remote from large cities & from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Residential urban community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban community (near relatively busy roads or industrial areas)	-5
Correction for Previous Exposure & Community Attitudes	No prior experience with the intruding noise	+5
	Community has had some previous exposure to the intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good	-5
	This correction can be applied for an operation of limited duration and under emergency circumstances; it cannot be applied for an indefinite period.	-10
Pure Tone or Impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+5

The adjustments applied to the CNEL to obtain a normalized community noise equivalent level (NCNEL) for communities adjacent to each plant are summarized in Table 4.2.4-3. The NCNEL thus obtained is plotted in Figure 4.2.4-1 which is a presentation of the correlation of the NCNEL with community response. The community response information was gathered during the behavioral phase of this study. Also included in Figure 4.2.4-1 is a mean line computed from values of normalized community noise exposure levels calculated for 55 case histories from the literature and the files of Wyle Laboratories and L. S. Goodfriend & Associates. Note the agreement obtained for data where there is sufficient noise to cause single threats of legal action or sporadic complaints. Where the noise is just noticable the data deviates from the mean. The NCNEL from the automobile assembly plant community is farthest from the mean. One must ask why, with the levels of NCNEL so great for the automobile assembly plant community, sporadic complaints weren't generated? This deviation from the mean line further reinforces our earliest contention that complaints may not be a good indicator of community impact, since it is known that industrial neighbors may not object to plant noise even at fairly high levels.

Since the mean line was constructed for only 55 case histories to which we might add five more from this study, the results

Table 4.2.4-3 - Adjustments Applied to CNEL to Obtain NCNEL for Communities Adjacent to Each Plant

Plant	CNEL[a]	Season	Attitude	Duration	Background	Pure Tone/ Impulse	NCNEL
Glass Manufacturing	62.2	0	0	0	+5	0	67.2
Oil Refinery[b]	66.8	0	-5	0	-5	0	56.8
Power Plant[c]	69.8	0	-5	0	-5	0	59.8
Automobile Assembly	64.1	0	-5	0	0	0	59.1
Can Manufacturing	67.2	0	-5	0	-5	0	57.2

(a) Obtained by Energy Averaging CNEL for Each Measurement Location

(b) Location Number 1 Not Considered Due to Chemical Plant Noise

(c) Gas Turbine Not Operating

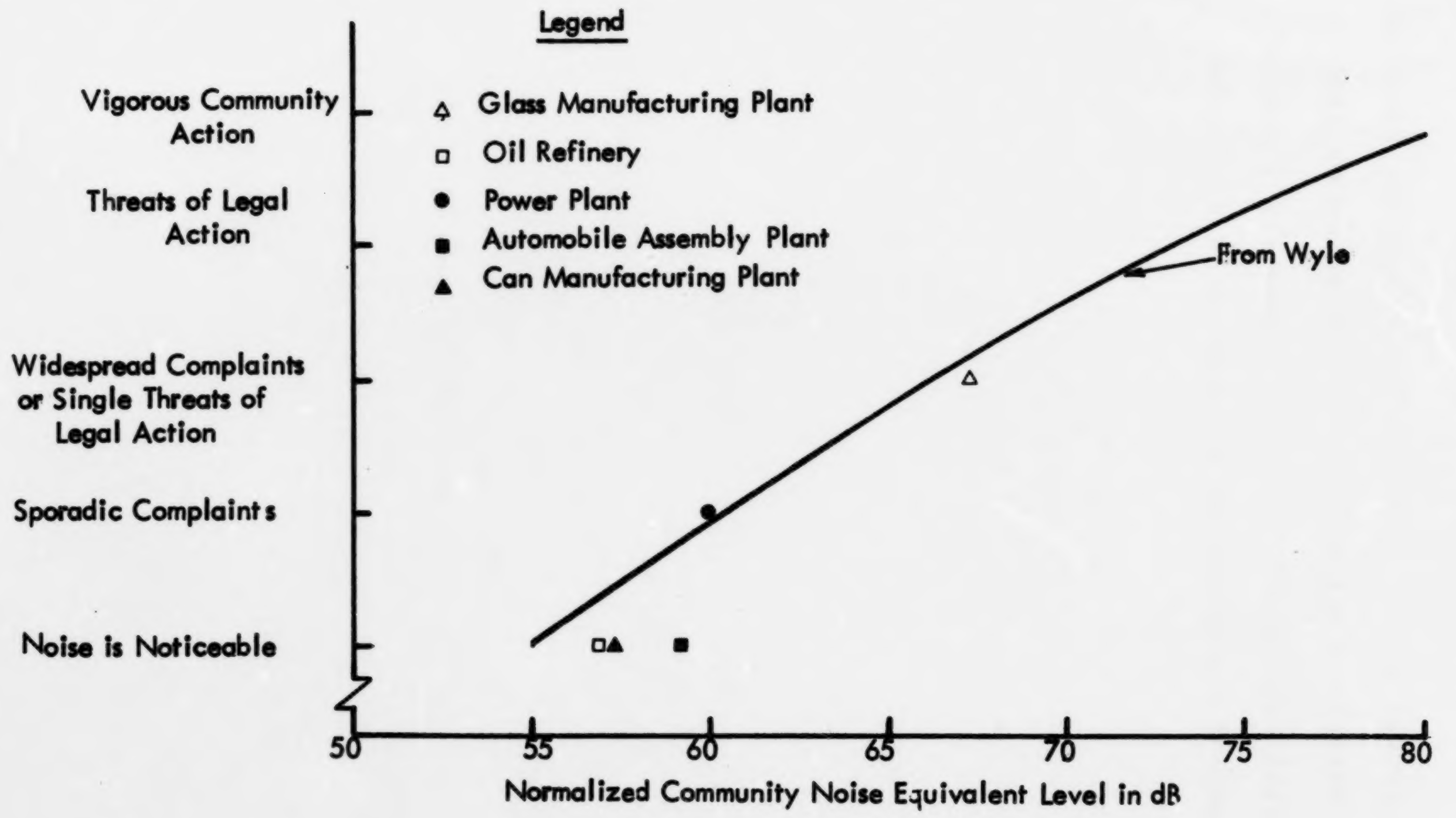

Figure 4.2.4-1. Correlation of the Normalized Community Noise Equivalent Level With Community Response.

perhaps are questionable. Further investigation into the correlation between a rating system such as normalized community noise equivalent level and community response using the complaint history as a criteria is suggested.

5. ATTITUDES TOWARDS NOISE LEGISLATION

5.1 Of the Industrial Plant

For the five industrial plants visited:

(a) Power Plant,

(b) Can Manufacturing Plant,

(c) Automobile Assembly Plant,

(d) Glass Manufacturing Plant, and

(e) Oil Refinery,

management awareness of current Federal, state, and local government noise regulations ranges from "barely aware" to "fully cognizant." Their information regarding noise legislation comes from other than plant personnel, such as insurance companies and the corporate engineering and industrial hygiene departments. The exception is the oil refinery, which has an in-plant industrial hygienist.

The general attitude toward noise legislation, determined from discussions with plant management, is a good one. With one exception, management realizes the advantages accrued by noise abatement in both their employee and their community relationships. The can manufacturing plant management finds the Federal Occupational Safety and Health Act of 1970 objectionable. In lieu of application of engineering noise control as the Act requires, they have provided all plant personnel with fitted ear protectors.

The industrial plants which are part of large corporations (automobile assembly plant and oil refinery), have received authorization from corporate management to proceed with engineering noise control, indicating a healthy attitude toward noise legislation at upper management levels.

The power plant, a part of a state-wide power company, receives engineering support from a centralized corporate facility. Staff members providing this support are aware of the benefits of the current noise legislation and support it fully. Management attitudes towards noise abatement in general and the legislation in particular must be good, for they have been authorizing noise abatement efforts for the past 20 years. This authorization includes hiring of qualified personnel and purchase of noise measuring and analysis equipment.

The glass manufacturing plant management and corporate management have only recently been made aware of their noise problem. Their attitude is confused. To assist them in forming an intelligent engineering noise control and hearing conservation program, they have retained an acoustical consulting firm which has recently completed a comprehensive noise survey and is now planning the second phase of the program.

5.2 Of the Community

Although noise is recognized as an environmental factor by each of the five municipalities in which the typical plants considered in this study were located, it appears that it occupies a low priority position with respect to community requests for regulations, or for regulations initiated by the municipalities. While one municipality has been conducting noise surveys in industrial plants and may prepare a new nuisance-type regulation if required, others have no plans to do anything other than enforce their existing nuisance code or wait for state guidance for the development of new uniform codes.

Municipal activities concerning noise regulations, it was found, are the province of either the board of health or the police department with any unusual matters usually being referred to a member of the town council or office of the mayor.

Little interest was expressed by any officials contacted regarding Federal activity in the area of noise control legislation.

The results of discussions with township officials, such as town councilmen, city clerks, board of health officials, and police are summarized in the following paragraphs.

The town in which the glass manufacturing company is located has a nuisance ordinance covering noise, but has no specific noise ordinance. There has been some talk among the town council regarding the possibility of a noise ordinance, but no official action is in progress at present. In general in this town, most complaints have been very unofficial, consisting of informal discussions with council members by plant neighbors. Council members feel that they have had excellent cooperation from local industries, thus precluding the need for strong legislation.

Information obtained from the city clerk's office of the town containing the oil refinery indicates that there has been no record of any city council action regarding noise complaints for the past 10 years. A noise ordinance passed in October 1969, contains no noise level requirements, but instead makes unlawful

> "...any loud, unnecessary or unusual noise, or any noise which either annoys, disturbs, injures, or endangers the comfort, repose, health, peace of safety of others..."

The municipality in which the power plant studies were located had previously enacted a stringent noise control regulation, but this had been successfully challenged by persons accused of violating it. Since then, the State of New Jersey has been reported to be considering preparation of a standard form of regulation for use in municipal codes. In view of the proposed plan by the State of New Jersey to develop a uniform code, this municipality has suspended further activity at the local level.

The town containing the automobile assembly plant currently has general standards and regulations in its sanitary code concerning noise and nuisances. The department of health is now studying existing noise regulations of various cities and townships to be used as a guide by the township committee in the preparation of a new noise regulation.

A member of the planning board of the city containing the can manufacturing plant has recently completed a study of noise ordinances from many towns and cities in their state. This member reports that most towns and cities are doing little at the present time to change their noise ordinances. Instead they are waiting for state government to issue guidelines and recommendations. The board of health at one time attempted to set stringent ordinances which were successfully challenged.

6. NOISE REDUCTION PROGRAMS FOR INDUSTRIAL PLANTS

6.1 Introduction

The noise of an industrial plant, or plant noise plus surface transportation noise, contributes to the residual noise level in its community. Industrial noise is a local problem with each plant presenting individual intrusive characteristics which may not be comparable on a nationalwide basis. The plant location, community residual noise levels, and other sources such as major highways, airports, or construction activities contribute to the community climate. The case studies of industrial plant noise, while only a small percentage of the total industrial establishments, indicate that plant noise may not significantly impact upon the community. It appears that noise due to construction job sites, surface transportation, and aircraft exceeds in importance the contribution of industrial plants to community annoyance. At some future date, when noise abatement efforts applied to the above primary sources successfully reduce their levels, the contribution of industrial plant noise to the community residual levels will rise in importance. Then the goal of an industrial plant exterior noise abatement program may be the elimination of community complaints, although complaints or lack of complaints may not be a satisfactory indicator of the impact of plant noise on its neighbors.

It is anticipated that, in general, industrial plant noise reaching the community will not increase in the near future, but may in fact decrease, as noise abatement efforts required by the Occupational Safety and Health Act of 1970 become effective. But it must be pointed out that at specific locations where interior plant noise is reduced by simply locating the noise sources outdoors, the impact upon the community may increase.

6.2 Motivation

A number of significant factors which motivate industrial plant management to institute noise reduction programs will be discussed.

In the past, the primary motivation was the desire to be good neighbors and to maintain good community relations. It was found through discussions with industrial plant management that the large corporations of national stature are particularly sensitive to public relations. Funds and personnel are quickly made available to solve noise problems which the plants are made aware of by community complaints. Often plant management anticipates community reaction in applying local corrective action to reduce or eliminate the noise problem.

The site selection and industrial plant design processes together with the local government control of industrial zoning provide the motiviation and the early opportunity to institute noise abatement efforts. It is known that this early phase of industrial plant development provides the most economic period for application of noise reduction techniques. Local municipal pressures in the form of noise nuisance ordinance and, more recently, realistic zoning regulations have produced legal pressures to reduce plant noise. The zoning ordinance for the township in which the glass manufacturing plant of the case study is located, is representative of the type currently being instituted. This ordinance was revised in June 1966 and contains the requirements shown in Table 6.2-1.

Table 6.2-1 - Representative Noise Regulations (Zoning Ordinance)

Octave Band* Hz	Sound Pressure Levels in dB re $20\mu N/m^2$ Daytime	Nighttime
20-75	75	65
75-150	60	50
150-300	54	44
300-600	48	38
600-1200	45	35
1200-2400	42	32
2400-4800	39	29
above 4800	36	26

*Bands are presented as shown in the ordinance

An additional motiviation to reduce plant noise, alluded to earlier, is the requirements of the Occupational Safety and Health Act of 1970. This act forms the legal basis requiring the initiation of noise reduction programs for in-plant noise sources. That these in-plant noise sources may be sufficiently high not only to be hazardous to employee hearing, but also to contribute to the total industrial plant exterior noise picture can be seen in Table 1-1.

Consumer pressures, which exist for other sources, are not a motivating factor for plant noise reduction. The consumer is interested in the end product and not in the manufacturing process producing the product.

6.3 Methods of Approach

The potential for reducing interior and exterior noise of industrial plants is in general excellent. The engineering and architectural techniques for reducing this noise along its transmission paths are known at present. However, reducing the noise at its source may be difficult and expensive, often resulting in the degradation in performance of the equipment, machine, or process.

For new plants, application of noise abatement techniques during site selection and plant design, together with realistic noise level requirements for new equipment being purchased, provide an economical and effective means for achieving noise level goals. Many companies are currently developing purchase specifications which contain noise level requirements. An example of this is the parent corporation of the automobile assembly plant discussed in Section 3.4. This corporation, one of the "big three" automobile manufacturers, requires suppliers to perform noise studies at the manufacturer's location under simulated production conditions prior to shipment, to assure compliance with company standards.

An existing plant must achieve noise goals by application of noise reduction techniques to the acoustical transmission path, as it generally proves to be difficult and expensive to reduce the noise at the source. Noise of ventilation and blower systems which terminate outside a building may be reduced by application of mufflers, acoustical louvers, or simple barriers. Often relocation of the intake or exhaust to take advantage of noise directivity solves the problem. Furnace noise evident at power plants and oil refineries has been reduced by redesigned burners combined with mufflers at the inlet to the fire box.

Noisy areas inside plants have been effectively reduced by application of mufflers, vibration isolation, acoustical area treatment, or enclosures. A systems approach must be utilized to insure that all the major noise sources are abated. If one noise source of a group of noise sources is left untreated, the results of the noise reduction program may prove to be insignificant.

6.4 Future Commitment

The case studies discussed in Section 3., though representing only a small portion of the total industrial activity in the country, illustrate the range of industrial commitment to noise reduction programs.

Plans for further noise suppression at the glass manufacturing plant are being developed by their acoustical consultant. Funds on the order of $12,000.00 have been committed for noise abatement at this plant, and approximately $50,000.00 per year has been committed for central corporate noise research. Noise abatement efforts at the oil refinery and power plant will be continued at their present levels, with emphasis given to developing improved equipment purchase specifications. One of the "big three" automobile manufacturers, mentioned previously, has budgeted $2,000.000.00 for noise control efforts in 1971, and plans to budget approximately $4,300.000.00 in 1972. The can manufacturing company has no future noise suppression program.

6.5 Plant Noise Control Programs (Past,Present and Future)

Glass Manufacturing Plant

Essentially no planned noise abatement programs were undertaken at this plant or by the corporate engineering facility. Noise control measures were initiated by community complaints. Due to a community complaint, a cinderblock housing was placed around their forced air blowers. The inlet to this housing contains an inlet silencer. Also due to a community complaint, acoustical louvers were installed at the ground level exhaust from basement mold cooling fans.

Community complaints resulted in the township retaining an acoustical consulting firm. Daytime and nighttime noise measurements were made at the property line of the plant and at one location in the community. These data indicated that the local township noise ordinance was exceeded both at the property line and in the community. These results were reported to plant management and an acoustical consulting firm has been retained. A comprehensive noise survey was recently completed and the second phase of the effort is now being planned. Plant management is awaiting the results of this program for guidance for future noise abatement and hearing conservation programs.

Within the past year the corporate research engineering group has assigned one man to noise control for equipment being designed for use in the glass manufacturing plant.

The corporate research engineering group will actively undertake a noise abatement program of about one and one-half man years per year. One man will be assigned to conduct noise surveys.

Plant management anticipated that the acoustical consulting firm they have retained will aid them in planning an effective hearing conservation and noise control program.

Oil Refinery

A consulting firm was retained in 1951 to perform a noise survey within and around the refinery. When it was discovered that excessive noise was being generated by a catalytic cracking unit stack, a muffler was designed (in-house) and installed. This effort reduced the noise to a more acceptable level. This stack was 250 feet high and was a serious source of noise in the nearby community.

An audiometric examining program was begun for employees in 1952. Maximum allowable noise levels were prescribed for in-plant and property line locations in 1956. These levels were selected after careful research by the corporate noise research group. The same year, a noise dosimeter was developed, again by corporate research, to evaluate worker exposure to noise.

The company has developed Original Equipment Manufacturer (OEM) noise level data requirements. As part of sales proposals, vendors must measure and report equipment noise levels. In addition, vendors must list permissible exposure levels (A-weighted and octave band) at the worker's position relative to the machine or equipment.

Plant noise design criteria have been developed to assist plant engineers in meeting community noise level requirements and worker exposure limits.

Noise level maps of the plant containing A-weighted and octave band level data which describe the noise level distribution around the plant grounds, are maintained and updated at prescribed intervals.

An extensive audiometric examination program is maintained. All prospective employees are tested before being considered for employment. Tests are repeated every two years for employees under 40 years of age, and annually for employees over 40 years of age. If the under 40 employee is known to be exposed to above average amounts of noise, he is retested annually. Examinations are given to employees being terminated or those retiring.

A wide variety of hearing protection devices are made available at the industrial hygiene office. Employees entering high noise areas are expected to use them. Good cooperation from employees regarding hearing protection devices has been observed.

A continuing effort at the refinery and corporate research headquarters is under way to develop and implement as complete a noise abatement program as is possible. The corporate research headquarters has assisted the refinery in 16 to 18 noise control problems in the last few years.

The refinery and corporate research headquarters plan to continue their present efforts. Projects are continually under way to develop new noise control techniques which apply to a broad range of refinery noise sources. Purchase specifications are being developed to limit noise levels of computer peripheral and data processing equipment being introduced to refinery operations.

The American Petroleum Institute has retained an acoustical consulting firm with the objective of developing industry-wide noise abatement guidelines for:

- (a) hearing conservation,
- (b) speech interference,
- (c) community response,
- (d) product noise reduction,
- (e) plant design, and
- (f) equipment purchase specifications.

Power Plant

The corporation has maintained a central acoustics department for at least 20 years. Transformer substations, gas turbine, and steam generation sites have had noise surveys conducted prior to the final site selection. After construction is completed and equipment is operating at full capacity, noise surveys are repeated.

Due to community complaints in the past, walls i.e., acoustical barriers, have been constructed to obstruct noise radiating from forced draft blowers, valves, transformers, and switching stations.

No audiometric testing program for employees was instituted.

All surveys and noise abatement efforts were accomplished by the corporate acoustics group. No consultants have been retained.

Hearing protection devices (ear plugs or muffs), are available at the power plant. Use of the hearing protection devices is mandatory at the gas turbine installation. The power plant has recently acquired a combination "hard hat" and ear muff.

Three men experienced in field measurements are available from the corporate acoustics group on an "as needed" basis. One man is assigned noise projects full-time. Present projects, in cooperation with manufacturers, deal with the reduction of noise from machines and equipment, with special emphasis given to gas turbines and steam and gas-reducing valves.

Audiometric testing, as part of a comprehensive hearing conservation program, is being considered for future implementation.

Equipment purchase specifications will contain a noise level section. The noise level requirements for equipment and machinery are under study at present.

The reduction of valve noise is a high priority future effort. When accomplished, only quiet valves will be installed at power plants and a retrofit program will be instituted for replacement of existing noisy valves.

Automotive Assembly Line Plant

The parent company has been involved in hearing conservation programs on a national scale. Each component plant, e.g., stamping, foundries, automotive assembly, etc., has had a noise survey by industrial hygiene personnel. Magnetic tape recordings were made at each noise source and later analyzed.

In-plant corrections were accomplished by maintenance personnel if possible, or by consultants specifically retained for the problem. Reduction of pneumatic tool and hoist noise was accomplished using makeshift mufflers. A tire drop retainer noise was reduced by liberal application of automotive undercoat. Noise radiating into the plant from automatic air blow-off (for removal of dust, lint, etc.) was reduced by the use of an acoustical enclosure.

If engineering control is not sufficient or possible, then ear protection is required. A study was conducted in conjunction with the University of Michigan to evaluate ear protection devices.

At the assembly plant, personnel (safety superintendent) are trained in the use of sound level meters and are required to monitor all plant locations. Every effort is made to reduce the noise levels to below 90 dB(A), or personnel are required to wear ear protection devices. Corporate industrial hygienists periodically conduct a comprehensive noise survey to locate major noise sources and to reduce them by engineering noise control measures.

Corporate equipment purchase specifications at present, specify equipment noise levels to be used by assembly plant purchasing agents.

Wearing of ear protection devices will be mandatory effective 1 September 1971, in all plant areas where studies show noise exposures are in excess of the Federal Occupational Safety and Health Act's requirements. When the ear protection device program is fully implemented on a mandatory basis, there will be approximately 35,000 ear protectors in use company-wide.

Noise studies will be performed on machinery under simulated production conditions at the manufacturer's location to assure compliance with company standards before being shipped to the plants. Manufacturers have been very cooperative and are eager to install noise controls on their machinery or tools where required.

Based on engineering projects, plants have increased their budget allotments for noise control significantly. For example, almost $2,000,000.00 was budgeted for noise control in 1971. In 1972 this figure has been set at approximately $4,000,000.00.

Can Manufacturing Plant

No noise abatement effort has been accomplished in the past. No engineering controls have been established. The company's insurance carrier in 1970 recommended:

(a) All personnel in areas were 90 dB A-weighted is exceeded should be provided with ear protection until engineering controls are established.

(b) The apparatus area, where compressors and similar noisy machines are located, should be physically separated from the production area.

(c) Certain large and noisy presses should be acoustically isolated.

(d) Air exhaust from internal lacquer spray units should be provided with mufflers.

(e) A hearing conservation program should be inaugurated.

None of the above recommendations regarding engineering noise control have been instituted. Instead, a mandatory ear protection device program was instituted on 2 August 1971. All production personnel are fitted with molded ear protectors and are required to wear them at all times on the production floor. Approximately 80 percent of the employees were using the ear protectors during an unannounced plant tour.

7. NOISE ABATEMENT TECHNOLOGICAL ASSESSMENT

7.1 At the Equipment Manufacturers Level

Manufacturers of machinery and equipment that are major sources of noise within the typical industrial plants visited, were contacted by telephone or mail regarding their efforts (past five years, present, and projected five years) in the area of noise abatement. In addition, they were questioned as to the noise control equipment or technology not currently available that they, as manufacturers of noise-producing equipment, would like to have available.

Obtaining the information described above was difficult. Many more manufacturers were contacted than are reported here, due to this difficulty in obtaining technically reliable information. The results of this technical survey are reported for manufacturers of:

(a) compressors,
(b) pumps,
(c) furnaces,
(d) air-cooled heat exchangers,
(e) pressure-reducing valves,
(f) I.S. machines,
(g) industrial trucks, and
(h) blowers.

(a) Compressors

A manufacturer of large compressors (to 40,000 horsepower) of the type used in oil refineries, describes these units as being custom-designed and built, none being from a standard line of compressors. They indicated that though many customers included maximum noise level requirements with their purchase specifications, these noise specifications are given "lip-service." This manufacturer feels that their units are not too noisy, at least no noisier than their competitors; therefore, no appreciable effort is given to noise control. The have budgeted no effort for developing quiet compressors. In most installations, they indicate the major source of noise is due to the piping systems, and they do not consider this their responsibility. A noise consultant is part of their staff. His responsibility is to advise customers of noise abatement techniques, such as mufflers and pipe lagging, but it is not considered his task to aid in development of quiet compressors.

This manufacturer expressed the opinion that quieter compressors could be designed, but that in spite of purchase specifications containing maximum noise levels, must purchasers are not willing to pay the additional cost of the compressor that designing for lower noise levels would entail. When the custom-built compressor is found to produce noise at levels greater than anticipated, the customer is usually willing to relax his noise limit requirements.

A second compressor manufacturer indicated that this compressor division contracted with a private acoustical consultant in the past to specify and recommend methods to reduce the noise levels for about 30 or 40 non-standard machines. They have utilized acoustical panelling and enclosures in order to reduce the noise levels when required, but they do not modify standard compressors at the noise source in order to meet their customers' noise level specifications unless a customer writes a specific purchase order and is willing to pay for the research and development in order to accomplish this. This manufacturer has been forced by tighter acoustical specifications from their customers to study noise reduction for their units. There remains a question, however, whether they can remain competitive with a quieter product at a higher price.

Another division of the same manufacturing company, the centrifugal compressor division, indicates that they use the following techniques for the design of air compressors in order to minimize the noise generated:

1. Gears are a major source of noise, therefore, gears of good quality are essential in order to reduce the noise level.
2. Direct line seals are used.
3. The compressors are made of cast iron as opposed to fabricated steel, because this material has more inherent damping.
4. The radiating surfaces are minimized, and in the installation of the compressor, every effort is made to minimize the piping and/or ductwork.
5. Selection of proper accessories such as gear pumps, drive motors, etc., is accomplished.
6. Tighter noise level specifications from their vendors for components of their compressors are being required.

This division indicates that the parent company has allocated funds and is sponsoring a research and development program by an outside consultant. The purpose of the program is to conduct a technological assessment of the problem and provide recommendations to point the way for future development of turbo-machinery noise reduction.

In order to stay competitive, they feel quieter products must be developed. More people are aware of the problem of noise, and therefore, a quieter product is a good selling feature as contrasted with other features that sold compressors four or five years ago.

The reciprocating compressor division of a third company has not redesigned any compressors, but has built enclosures to reduce the noise levels to 85 dB(A). They also tested several silencers on the air intake and now provide their customers with silencers or enclosures, which they sell as options.

A fourth manufacturer indicates that a full-time sound and vibration consultant is on their staff. Their research and development laboratory has made major changes in their entire product line of air compressors. They have indicated that one of their new products, which is skid-mounted, does not require a foundation and generates 50 to 75 percent less noise than conventional reciprocating or centrifugal compressors.

(b) Pumps

The first company contacted manufactures a variety of small-to-medium size pumps. Some pumps are modified to meet state and local noise ordinance regulations when complaints occur. During 1970, they spent $20,000.00 to reduce the noise for one line of pumps. The company is aware of noise pollution problems and regulations, and they retain an outside consultant when needed.

A second company contacted indicates that they have done a considerable amount of work with the problem of structureborne vibration, but not nearly as much for the airborne noise problem. They have worked on several design modifications, such as bearings, hydraulics, couplings, etc., leading towards the optimization of efficiency and noise reduction.

In the past, a third pump manufacturer's noise abatement research and development was associated with ultra-quiet pump operation for application aboard atomic submarines. At present, they are experiencing a gradual trend towards tighter noise specifications for special pump operations in schools and hospitals, rather than for industrial applications. The drive system of their pump is the major source of noise, provided that the pumps are operated in accordance with company specifications. This holds true even for large centrifugal pumps and circulators, as they are normally driven by large electric motors with forced air cooling, thus generating a great deal of noise. In addition, the pumps are sometimes driven by diesel engines which are exceedingly noisy if not properly muffled. Gas turbines with speed-reducing gears tend to generate noise at high frequencies. If the pump is not operated within specifications set forth by the manufacturer, it can lead to pump cavitation which creates a great deal of fluidborne noise as well as mechanical vibration. There is usually a sacrifice in pump efficiency for a quieter operation, which unfortunately, most customers are not willing or have no desire to pay for.

Another major manufacturer of large circulating pumps used in nuclear power plants and also fossil fuel power plants was contacted. They manufacture a "canned motor pump" which is sealed in a totally enclosed vessel and has no shaft seal in the conventional sense. This manufacturer has done a great deal of research and development under government contract to reduce the noise emission generated by pumps. Various types of approaches taken (for the canned motor pump), are:

(a) Use of pivoted pad radial bearings in lieu of sleeve bearings.

(b) Use of multivaned impellers instead of conventionally designed impellers.

(c) Use of mufflers on the motor exhaust to minimize windage noise.

This company has a full staff in their acoustical research laboratory. Some of the noise abatement research which they have accomplished has been financed by outside industrial and government contracts, while most has been financed from company overhead expenses.

(c) Furnaces

The company which manufacturers furnaces for oil refineries has conducted, and is continuing to conduct, research and development on furnace noise abatement. Research on the mechanism of combustion noise has resulted in a new burner design which lowers the sound pressure level by 15 dB. Air inlet mufflers have been developed for these furnaces. Using a combination of new burners and inlet mufflers, they have reduced the sound pressure level of one particular furnace approximately 15 to 20 dB. Their mufflers, however, are uniquely designed for each furnace installation, due to the variation in construction details from unit to unit.

(d) Air-Cooled Heat Exchangers

A manufacturer of large air-cooled heat exchangers of the type used in oil refineries indicated that 80 percent of the purchase requests they now receive have maximum noise level specifications. Some of these specifications are more stringent with regard to noise levels at the operator's location than the Occupational Safety and Health Act of 1970 requires.

A typical heat exchanger fan has a diameter of 10 to 14 feet, with a tip speed of 12,000 feet per minute. Blade passage frequency is 20 to 30 Hz, which is too low a frequency to be a major problem. Most of the noise due to this fan is from turbulent air flow interacting with blades and heat exchanger surfaces, and the vortex shedding from the blades. The noise level for a typical unit before noise control efforts have been applied is 91 dB(A).

Basic noise control techniques which this manufacturer applies are:

1. Reduction of fan speed and horsepower.
2. Increase of air flow and heat exchanger surface areas.
3. Sound absorption inside the unit.
4. Damping of panel vibrations and use of a patented blade tip seal developed to prevent back flow between the blades and the shroud, providing better efficiency at the desired low speeds.

For a given use, the noise can be decreased by increasing the area of the heat exchanger, thereby decreasing the air velocity through the unit. The reduction of fan speed and increase in area causes the fan unit to approach that of a natural-draft heat exchanger. The degree of quiet from a particular unit is a function of the price the customer is willing to pay. In general, the cost of noise reduction is 1.5 to 2.5 percent of the basic price of the unit per decibel of noise reduction. A reduction of 10 decibels below the Occupational Safety and Health Act of 1970 requirements prices a unit at two to three times the original cost. Field modifications to achieve noise abatement for older heat exchanger units are exceedingly difficult. This company has been only able to achieve a three to five dB noise reduction for these older units.

(e) Pressure-Reducing Valves

The first manufacturer contacted has had an extensive research and development program in the field of valve noise abatement for the past three years, and plans to continue the program in the future. The purpose of this program is to be able to predict when there will be a field noise problem, and to have the proper techniques available to treat it. They have provided a variety of silencers to their customers. In addition, they have developed several noise source treatments, such as "whisper trim," which is a specially designed body trim that is an accessory to a standard valve.

A second manufacturer of pressure-reducing valves varying from one-eighth inch to 12 inches in size is well aware of the noise problem and at the present time is evaluating their entire product line for future redesign consideraions. By the end of the year 1971, they hope to be able to market an entire line of redesigned valves which they feel will be much quieter.

This company has two engineers who are continually studying the problem of noise from the installation, piping, and control aspects, as well as from the redesign or modification of the valve itself. They enclose an installation diagram with each valve which, if followed, provides maximum efficiency and minimum noise. Occasionally they recommend specific designs with different accessories such as caps or plugs in order to reduce the noise or vibration problem still further. These accessories are provided at no charge, if the customer is not satisfied. The sales department always consults with the engineering department when they quote a valve installation if they feel a noisy installation may result. Occasionally some customers do not follow their advice, constrained by the fact that the proposed installation may not be economical. This company feels that a quieter valve is not competitive at a higher price than conventional valves at the present time, mainly due to their customers unwillingness to spend the extra money. This is especially true if their purchase order contains no noise criteria. However, they feel that in the future, noise will be given greater consideration by the customers and by industry in general.

A third manufacturer has conducted an extensive research and development program on the problem of noise abatement of pressure-reducing valves. Their sales department has a mini-computer programmed to predict the sound level (within plus or minus five dB0 of a valve when different parameters such as inlet pressure, flow, pressure differential, diameter, etec., are used as input. This computer is utilized to help the sales department recommend to their customers the proper valve and accessories needed for a quiet installation. Treatment of noisy valves with pressure reduction ratios of 5 to 1 can be handled easily by means of silencers, but higher ratios present problems.

They recognize that a major noise problem is the generation of shock waves as a result of the pressure differential and velocities in the sonic region on one side of the valve and subsonic on the other. Silencers do not prevent the generation of shock waves, therefore they are not the answer for this type of problem. One theory provides a rule of thumb that the velocity of the flow through valve should be limited to one-third of the speed of sound in order to minimize or prevent the generation of shock waves. New techniques such as deaerators have recently been developed.

(f) I.S. Machines

I.S. machines used by glass manufacturing plants are often made by a division of the glass manufacturing company. The manufacturer of a class of I.S. machines similar to those in the glass manufacturing plant was contacted and indicated that some funds are allocated for noise control, but that much of this work is being done at one of their European plants. They do market a line of mufflers for these machines, and have made several design modifications to the basis unit with noise abatement as the objective. Mufflers have been developed that reduce spool valve exhaust noises on scoop, baffle, and blow-head mechanisms on two types of machines. The noise from blow-mold, spool valve, and blank mold booster cylinder quick exhaust valves on one class of machines can also be reduced by mufflers. Noise level reduction of the valve block requires replacing the one piece tappet valves and bushings with two piece valves and bushings that exhaust into an air chamber at the rear of the valve block. Nylon plates are used to silence mechanical action of the valve levers. This newer type valve block has been standard on one class of I.S. machines since 1962, and is now standard on the other. In addition to built-in noise suppression, this valve block provides savings in compressed air requirements by reducing air leakage. The design of the two piece valves and bushings also provides for increased wearability. Noise suppression equipment its optional and is easily installed on both types of machines upon customer request. For older equipment, mufflers and related parts complete with assembly and alteration drawings for the I.S. mechanism can be supplied in kit form at a cost of $75.00 per section (valve block conversion not included) for both types of machines. The valve block conversion, sepending on the vintage of the old valve block and the amount od modernization required, costs from $285.00 to $890.00 per section. In lieu of converting the old style valve blocks, new valve blocks can be purchased.

Another manufacturer of I.S. machines similar to the type used in the glass manufacturing plant, does not market a line of silencing devices,but indicates that they are doing research and development to reduce the noise of their machines. They have a laboratory unit which they use to test new design modifications. They also do some noise control consulting for their customers.

(g) Industrial Trucks

A major manufacturer of industrial trucks was contacted. They indicated that essentially no noise abatement efforts were accomplished until about one-and-a-half years ago. They Occupational Safety and Health Act of 1970 made them aware of noise as a problem. An industry-wide (Industrial Truck Association) test procedure was adopted which required noise measurements to be made at the operator's ear plus 6, 12, and 18 feet from the side of the vehicle. These measurements are made at full speed, maximum load, and no load, plus during a "drive-by."

Muffling of engines was accomplished by purchasing off-the-shelf mufflers. Trucks were quieted on a "cut and try" basis by shrouding the engine compartment. At present, fan noise is the major source of noise for LP gas vehicles, while high-speed DC motors are the major source of noise for electric vehicles. Power-steering pump noise also is a problem for the electric vehicles, but the noise of the electric vehicles is well below the requirements of the Occupational Safety and Health Act of 1970.

One-third octave band analysis equipment has been purchased and is used with the above test procedure to evaluate the truck noise and to determine noise sources. Their own industrial trucks and competitive units are both being tested. They are in the midst of this program which they anticipate will describe their problems and help generate future goals. Two engineers full-time, plus additional help on a part-time basis, are engaged in this program. The manufacturer feels that other manufacturers of industrial trucks are engaged in about the same level of effort.

(h) Blowers

A blower manufacturer contacted indicated that they sell a fan silencer as an accessory to their industrial fans, but are not quieting their units. They feel that there is a future market for a quieter but more expensive fan. At the present time, the market for quieter fans is minimal. An increasing trend of concern on the part of their clients with regard to the problem of noise is indicated.

A second manufacturer of industrial fans, blowers, and exhaust systems indicated that since they are in the small business category, they do not manufacture any noise reduction accessories; but instead they recommend that their clients use acoustical consultants.

A third manufacturer of fans, blowers, and exhaust systems feels that the fundamental noise due to fans will not be reduced by any significant amount due to fan design. All their efforts are being directed to the addition of attenuation through muffling devices and not to the source studies. They have been reviewing the research which has been done with regard to noise for turbines and aircraft propellers, expecting to adapt some of these developments to fan technology.

In order to meet the Occupational Safety and Health Act of 1970 requirements in the future, they feel they have no choice but to supply the fans as a package with attenuators and mufflers as part of the system. The difficulty that they are having with their clients with regard to the Occupational Safety and Health Act of 1970 requirements is that their customers specify these requirements, but do not indicate the environment into which this equipment is going to be installed. This manufacturer is attempting to educate their clients to make them aware of the need for specifying environmental conditions as well as the other performance parameters of the fan.

7.2 State-of-the-Art Noise Abatement Technology

7.2.1 Introduction

The general approach to noise control in industrial plants is well established. However, because of the multiplicity and complexity of industrial plant noise sources and their associated environment, solutions to industrial noise problems have been obtained more or less on an empirical basis. In other words, an analytical solution to every industrial noise problem does not exist. Experimental investigations of the noise source should form part of a noise control development program. Excessive noise in existing industrial plants can be reduced (to conform to established criteria for hearing damage, annoyance, or speech communication) by applying current state-of-the-art noise abatement technology. However, corrective measures for existing noisy industrial plants prove to be more expensive in dollars per decibel of noise reduction than incorporation of noise abatement features in the original design of the plant equipment. One of the significant advances in noise control technology is the systems approach concept as applied to noisy industrial machines. The systems components in such an approach are the noise sources, the multiplicity of transmission paths, and the receiver. Noise abatement methods describing the current state-of-the-art are discussed for the source and transmission path. The noise abatement approach as applied to major industrial noise sources, such as gas turbines, compressors, blowers, etc., is also discussed. One might conclude that using the present state-of-the-art in noise abatement, it is possible to control industrial noise and thus provide satisfactory in-plant and community environments.

One of the more important considerations for industrial plant planning for noise control lies in the initial design of new plants and the modernization of existing ones. Architectural noise control concepts have been successfully applied to this field for the past two decades. Some general considerations useful in the engineering control of industrial noise are enumerated in the following discussion.

For good planning in noise control, it is important to know the noise characteristics of each machine, process, and environment. For this to be meaningful, engineering specifications for the design and selection of equipment or machinery should include noise level requirements. Towards this end, two working groups of the American National Standards Institute are responsible for the development of basic acoustic measurement standards applicable to sound radiating by stationary machinery under field and laboratory conditions. (ANSI Working Groups S1-W-51 (S3) and S1-W50 (S3)). A list of standards and specifications for the rating and measurement of machinery noise sources is given in Appendix C.

Further environmental noise levels should conform to the Federal regulations requiring that the noise characteristics of the equipment be known. It is important to know and compare noise level outputs of equipment, their prices, and other factors before it is purchased for installation. The location of the machine inside the plant also involves several considerations such as the type of noise emitted (whether intermittent or continuous), how many people other than the operator will be exposed to noise, whether the equipment can be enclosed without affecting its operating efficiency, etc. The location of the equipment within the plant is an important factor that needs careful study in the initial planning stages.

7.2.2 Source Noise Control

Engineering solutions to reduce noise in machinery involve many different techniques. However, in order to understand these techniques, it is essential to understand the mechanism of noise generation. Machinery noise may originate from one or more of the following important factors: impact, friction, fluid turbulence, forced vibration, electromagnetic effects. The following discussion will be limited to the noise reduction techniques as applied to the above factors.

Impact noises are present in most metal fabricating operations and are proportional to the magnitude of deceleration at impact, size of the impacting surfaces, mass, stiffness, and damping[2]. The reduction in deceleration may often be achieved by interposing soft elastomeric material between the hard impacting surfaces. This may not be done when the impact is the desired machine output. Reduction of impact noise may also be effected by use of a smaller force applied over a greater period of time, rather than a greater force for a shorter duration[3]. Impact noise may also be reduced by vibration isolation of the driving source and by damping treatment of resonant machine parts.

Major sources for noise generated by frictional effects are: gears, bearings, extrusion presses and sliding linkages. The usual method of reducing frictional noise is by lubricating the moving parts, improving the fit (gear or bearing geometry), and damping.

The noise generated by an air ejection system such as pneumatic tools, jet engine exhausts, etc., is due to the high velocity fluid flow of the jet which produces turbulence when mixed with the ambient air. There are two types of fluid flow jet systems: one in which the ratio of the upstream pressure from the jet nozzle to the ambient pressure is less than approximately 2:1, and the other in which this ratio is greater than approximately 2:1[4]. The noise of the jet for the first type of flow varies between the 6th and 8th power of the stream velocity and directly with the area and density of the fluid[5]. Therefore, substantial reduction in the noise levels may be achieved by a reduction in velocity. The second type of jet is known as choked flow. In this case, the flow through the nozzle is sonic, but downstream of the nozzle the flow becomes supersonic, resulting in shock wave formation. Due to shock wave formation, the noise generated may be greater than that calculated from the velocity, area, and density mentioned previously. High pressure air ejection systems are examples of choked jet flow, and for this case the simplest way to reduce noise is the resort to mechanical rather than pneumatic ejection. Another method is to reduce the velocity but retain the thrust by utilizing multiple nozzles. Since the width of high velocity portion extends only up to approximately two jet diameters[6], maximum thrust of the air ejection system can be obtained by accurately aiming the jet stream at the target. Further turbulence caused by sharp bends or other obstructions upstream of the nozzle can be reduced by streamlining the jet stream path.

Vibration can be caused by unbalance of rotating members, and by changes in velocity of oscillating parts, such as bell cranks, and of reciprocating components, such as pistons or rams. The periodic force resulting from unbalance of rotating members increases with an increase in the speed of rotation. It it important therefore, to minimize the magnitude of the unbalance by dynamic balancing. Because increasing speed results in greater forces and higher noise levels, it is useful to use a larger, but slower machine: an example is a large diameter blower running at a slower speed in lieu of a smaller diameter unit operating at a higher speed.

Finally, noise in machinery may be electro-magnetic in origin. In electro-magnetic devices, vibrational forces are generated by the attraction and repulsion of magnetic fields. Reduction of this type of noise may be accomplished by proper redesign or by reducing the effect of the leakage flux. Replacing magnetic materials which are not part of the desired flux path with non-magnetic materials is a design objective. The directional property of magnetic fields may also be used to reduce the noise effects on nearby parts. An excellent discussion of magnetic noise is presented in Reference 7.

General methods for reducing noise at the source are described in Table 7.2.2-1.

7.2.3 Transmission Path Noise Control

Noise sources may be coupled to other structural members through solid, air, or magnetic paths, which in turn may vibrate and reradiate sound. The transfer of energy through solids or air is common to most machinery.

Reduction of magnetic coupling may be achieved by removing unnecessary magnetic materials or replacing them with non-magnetic materials such as brass, aluminum, or non-magnetic stainless steel.

Table 7.2.2-1 - Basic Techniques for Machinery Noise Control

(At the Source)[2]

Impact	- Reduce Deceleration, Damp Source Pieces, Reduce Hardness of Impacting Surfaces, Reduce Size of the Source.
Friction	- Damp Source Pieces, Reduce Hardness or Rubbing Surfaces, Reduce Source Size, Lubricate Surfaces.
Fluid (Air) Turbulence	- Reduce Air Velocity, Remove Obstructions, Polish Rough Surfaces.
Forced Vibration	- Balance Parts, Reduce Acceleration, Add Tuned Dampers, Operate Off-Resonance.
Electro-Magnetic	- Reduce Leakage Flux, Remove Nearby Magnetic Materials, Orient Magnet for Minimum Coupling.

Since structureborne noise is common to most machinery, it will be discussed in some detail. Mechanical or structural coupling may be reduced by using a compliant link between the two vibrating members, which mismatches the impedance between the two paths. An example of this is the use of flexible hose in piping systems. Another method of providing compliance is by vibration isolation of the source from the radiating structure. The selection of vibration mounts must be made so that the resultant combination has low transmissibility. Excellent treatments of the transmissibility for vibrations and shock isolation are given in the literature[8].

When the transmission path or coupling is air, attenuation of the airborne noise may be achieved by suitable construction of partial or full enclosures. Whenever a machine or machine parts is enclosed, it becomes necessary to isolate the enclosure mechanically from the machine structure so as not to transmit acoustic energy via a vibratory path.

When the machine is located in a highly reverberant area, the resultant noise may also be reduced by treating the area surfaces with sound absorbing materials. In practice, the noise reduction achieved by this means is limited to approximately 7 to 10 decibels. Noise reduction obtained by the use of sound absorbing materials is useful when the exposed person is in the reverberant field. Excellent discussions of enclosure design and the transmission loss of structures are found in the literature[9,10,11,12]. Among the many transmission paths through which noise may be propagated are the special case of ventilation ducts. One of the requirements of a ventilation duct system is that the air flow and static pressure requirement be maintained, but the noise transmission through the system be minimized. These requirements can be satisfied by introducing acoustical attenuating devices. These devices consist primarily of a suitable reactive or dissipative muffler to obtain the required noise reduction. The acoustical performance of mufflers is affected by the high gas velocities,pressures, and temperatures that are usually encountered in industrial plants. For combating corrosion in industrial plants, mufflers may be provided with stainless steel or synthetic fibers as acoustical absorbent materials. A thorough discussion of the design of reactive and dissipative mufflers is available in standard texts and other publications[13,14,15].

Noise from the source may be transmitted to structures as mechanical vibration which may then radiate as noise into the environment. The response of a fibrating surface to airborne or structureborne noise depends upon the mass, stiffness, damping, and surface area of the structure. Radiating surfaces may act as noise amplifiers at resonance. In general, most mechanical structures have a greater number of multiresonance frequencies at higher frequencies than at lower frequencies. Noise reduction can be obtained by damping the resonant members, increasing stiffness or mass to shift the resonance frequency, and decreasing surface area.

The effectiveness of vibration damping materials depends upon their efficiency in converting vibratory mechanical energy into heat. Some materials have high internal damping. Sheet lead for instance,has more internal damping than sheet steel; however, it is not always possible to use lead as a structural material. In such cases, external damping material may be applied.

The theory of vibration damping is well known[16] There are three types of vibration damping: friction damping, homogeneous damping, and constrained layer damping. In friction or coulomb damping, energy conversion takes place through friction between the damping material and the vibrating surface.

Jute, cotton fibers, wood fibers, and foams are among the best friction damping materials. Glass fibers and other cellular and fibrous materials which have a high internal damping and high stiffness are effective homogeneous or extensional damping materials. The most effective damping materials in use at this time have a plastic base and are available in liquid or sheet form[17]. Constrained layer damping consists of a layer of homogeneous damping material or thin metal foil separated from the vibrating surface with an intervening layer of viscoelastic material. In constrained layer damping, the dissipation of mechanical energy is effected by shear motion of the constraining damping material.

Radiation of low frequency sounds may be reduced by using a smaller surface area. The use of perforated or expanded metal reduces the noise radiation from the sheet metal guards or cover pieces. It is also necessary to isolate a machine cover from vibration of the machine by use of resilient gaskets and grommets. The important concepts discussed above are summarized in Table 7.2.3-1.

7.2.4 Machinery, Equipment, and Process Noise Control

In the following sections, the generalized comments regarding

Table 7.2.3-1 - Noise Reduction Methods

I. Plant Planning
   a) Selection of Equipments
   b) Location of Equipments Within the Plant
   c) Location of Plant With Respect to the Community

II. Control at the Source
   a) Maintain Dynamic Balance
   b) Minimize Rotational Speed
   c) Decouple the Driving Force
   d) Reduce Velocity of Fluid Flow
   e) Reduce Turbulence
   f) Use Directionality of Source

III. Control of the Transmitted Noise
   a) Vibration Isolate the Source
   b) Enclose the Source
   c) Absorb Sound Within the Room
   d) Use Reactive or Dissipative Mufflers

IV. Control of Radiated Noise
   a) Increase Mass
   b) Increase Stiffness
   c) Shift Resonant Frequencies
   d) Add Damping
   e) Reduce Surface Area
   f) Perforate the Surface

source and transmission path noise control discussed in Sections 7.2.2 and 7.2.3, will be related to the major noise sources observed at typical industrial plants. These major noise sources are presented below in an order of priority for noise abatement efforts in the authors' opinions. The ordering procedure considers noise levels and widespread use of the equipment.

(a) Compressors
(b) Fans and Blowers
(c) Industrial Gas Turbines
(d) Pumps
(e) Pneumatic Tools
(f) Reduction Gear Systems
(g) Metal Fabrication (Presses)
(h) Furnaces and Flare Stacks
(i) Valves

(a) Compressors

The noise generated by axial flow compressors has been the subject of numerous investigators [24-38]. The noise from an axial compressor results from the interaction of the rotor with the stators or other obstacles in the flow path, and consists of discrtete frequency noise and broad-band noise.

The mechanisms of compressor noise radiation are essentially aerodynamic in origin and consist of two unsteady flow components: first, the wake field behind each blade, and second, the turbulence induced in these wakes. The wake interaction effects give rise to the discrete frequency noise radiation, while the turbulence in the flow gives rise to broad-band noise. The noise at the discrete frequencies are the tones appearing at the rotor blade passing frequency and multiples of this frequency, and are the predominant source of compressor noise. The discrete frequencies occur commonly in the range of 1000 to 5000 Hz, and are important therefore, in determining the subjective annoyance of compressor noise.

There are several methods of reducing the noise levels mentioned in the literature, such as increasing the number of rotor blades, using higher vane/blade ratios, and enlarging blade row spacings. Other variables remaining constant, experiments show that increasing the rotor blades from 20 to 80 reduces the noise generated at the blade passage frequency by approximately 10 dB; increasing the vane/blade ratio from 1.0 to 2.0 there is an 8 dB reduction in noise levels; and increasing the blade row spacing from 0.1 to 2.0 spacing/chord ratio there is a reduction of more than 10 dB at the blade passage frequency. Thus it is clear that the reduction of noise at the source is practicable and should be utilized in the design of compressor systems.

The noise characteristics of large centrifugal compressors has been the subject of recent studies[39,40]. The noise spectrum depends upon the drive configurations (gear reducers), compressor geometry, operating load range, and the fluid being compressed. High tip speed needed for centrifugal compressor operation can be achieved either by a large diameter impeller at low speeds, or a small diameter impeller at relatively high speeds. Compressor rotational speeds ranging from 3600 to 20,000 rpm are common, and the drive geometries employed in commercially available equipment have a significant effect on the noise produced. For example, the results of noise measurements over a capacity range from 90 to 4000 tons of refrigeration, show that the noise levels of these centrifugal compressors range from 89 dB(A), to 102 dB(A), independent of equipment size, drive configuration, fluid, or horsepower. The noise spectrum is a combination of broad-band noise associated with fluid flow turbulence and a series of discrete frequencies associated with the blade passage frequency of the impeller plus harmonics, electro-magnetic noises in the motor, mechanical unbalance in the drive configuration, and gear tooth contact frequencies. There is an increase on the order of 5 dB in the octave band containing the blade passage frequency (500 to 2000 Hz) for compressors working at loads less than 50 percent of full load.

At present, there is little information available on the reduction of compressor noise at the source. However, significant advances have been made in the art of muffler and enclosure design.

Application of current theory to the design of mufflers, vibration damping materials, fans, acoustical enclosures, etc., has resulted in the reduction of the noise of stationary and portable compressor systems. Noise from portable compressors producing 900 scfm of air at 100 psig, has been reduced from 100 dB(A) to 85 dB(A) by application of current noise reduction techniques to the airborne and structureborne transmission paths[41]. In a similar manner, large stationary compressor noise has been reduced from 106 dB(A) to 74 dB(A).

(b) Fans and Blowers

Fans and blowers are air handling devices which transfer energy to air without significant compression. Axial flow fans operate against little or no static pressure and are rarely used in industrial applications, where fans and blowers have to work against higher static pressures and where large volumes of air are to be moved. For this reason, centrifugal fans and blowers are generally used in industrial applications. The discussion in this section will be restricted to the study of noise abatement of centrifugal blowers at the source. Aerodynamic noise from the centrifugal blower consists of a rotational noise at the blade passage frequency and its harmonics and vortex noise, which is broad-band in character[42]. Noise generated from blowers (fans) has been studied experimentally and semi-empirically by various investigators[42-52]. In general, the broad-band aerodynamic sound power of a centrifugal blower is approximately proportional, for mach numbers less than 0.6, to the 5th power of blade tip speed, and the first power of mass flow[47,48]. It should be mentioned that as yet there exists no analytical model for the noise generating mechanism of centrifugal blowers. Experimental studies of the noise in centrifugal blowers show some marked improvement in noise reduction by proper design of the scroll, the cut-off clearance, and by sloping the tips of the impeller blades with respect to the scroll. For low noise levels, the scroll of a centrifugal machine should have the shape of an involute where the axial clearance increases in direct proportion to the angle traversed[42]. If the scroll clearance increases more rapidly, it causes abrupt pressure changes at cut-off and thus, increases the noise levels at the blade passage frequency. The cut-off clearance is an important factor in the design of blowers for low noise levels. The noise generated at the cut-off increases with a decrease in the cut-off clearance. Experimental investigation of noise produced by centrifugal blowers, with forward, backward, and radial blades at various speeds, capacities and pressures, shows that the noise level at the blade passage frequency and its harmonics may be reduced as much as 12 dB, either by locating the cut-off at the optimum clearance relative to the tips of the impeller, or by sloping the edge of the cut-off relative to the tips of the impeller blades[52]. By twisting of the impeller blades, broad-band aerodynamic noise may be reduced by 1 or 2 dB[52].

Important external sources of noise generated by the impeller are: housing radiation, inlet noise, and outlet noise. The noise radiation from the housing can be reduced by using heavier blower construction or by enclosing the blower. The inlet and outlet noise are reduced by using sound traps and mufflers at the inlet and outlet. The sound trap must be designed to meet noise reduction and air flow capacity requirements for the particular situation.

In an induced draft fan air handling system, the main source of noise is the discharge (exhaust) stacks. The intake is usually enclosed by ductwork and not a major source of noise. In the forced draft systems, fan noise emanating from discharge units is mostly dissipated within the air preheaters and boilers being supplied by the fan. In the forced draft fan systems, the fan inlet is the major source of noise. If the fan draws air from outdoors, the fan inlet noises must be reduced to eliminate noise complaints from neighborhood residential areas. Methods of reducing inlet or exhaust noise from forced draft or induced draft fan systems using silencers have been discussed in the literature[53,43,55]. Prefabricated silencer units to suit the particular situation are commercially available. Noise radiated from the shell of the fan housing and connecting ductwork can be reduced by using a heavier and stiffer shell, damping treatments, and by lagging the outside of the duct.

(c) Industrial Gas Turbines

There is very little information available in the literature on the reduction at the source of noise of industrial gas turbine installations. Gas turbines are used in industrial plants to drive other devices, such as generators, pumps, or compressors. The main sources of noise are the intake and exhaust of the turbine system. The noise at the intake is characterized by a high frequency shrill noise, corresponding to the blade passage frequency of the first stage of the compressor. For a 20 megawatt gas turbine generator installation, the intake noise level may be as high as 140 dB[18]. The noise at the exhaust is associated with the mass flow through the turbine exhaust, and is predominantly of a low frequency nature with a high frequency content corresponding to the blade passage frequencies of the turbine. In certain frequency bands the noise level due to the exhaust may be as high as 130 dB. Under these conditions, the noise level at large distances from a power plant may be higher than the ambient by as much as 15 to 40 dB during the daytime[18].

Intake and exhaust silencers are required to provide an insertion loss of 20 to 40 dB in the low frequency range, and 40 to 60 dB in the high frequency range to meet community noise criteria. For control of turbine noise, commercial silencers are available and range from six to 25 feet or more in length. A general discussion of the design considerations for silencers has been given in the literature[19-23]. In the past, the noise levels for gas turbine installations have been determined mainly by the manufacturer. Because of community reaction to industrial noise, the trend in the future may be that noise specifications for gas turbines will be developed by the purchaser.

(d) Pumps

The noise in hydraulic systems are primarily due to sudden changes in velcoity and pressure, cavitation, fluid turbulence, mechanical noise, and from pressure-reducing valves. The piping system readily transmits noise to support systems and surfaces which eventually radiate the noise into the environment. There is a little information available in the literature on the noise generated by pumps and hydraulic equipment and on the methods used for designing quiet equipment[56-60]. The present design methods are empirical. At present, there is a need for better understanding of the intrinsic pumping mechanism as it relates to noise and the effects of design variation on pump noise, since little quantitative information on these factors is available. Some of the methods used for reducing noise from pumps and piping systems are:

1. Vibration isolate pumps and motors to avoid transmission of fluid pressure pulsations.
2. Install acoustical filters designed for the pump or motor speed.
3. Use flexible hydraulic lines and flexible electrical connections in making connections to vibration isolate units.
4. Lag or apply external treatment to the piping system.
5. Enclose pump and drive unit in acoustical enclosure.

(e) Pneumatic Tools

Pneumatic tools have long been recognized as a source of high noise levels in industry. Pneumatic tools can be classified into three groups: rotary, piston, and percussion type. Rotary tools consist of grinders, polishers, screw drivers or drills; piston type devices are used in hoists, heavy duty drills, and nut runners; percussion type tools consist of chippers, scalers, riveters, and pavement breakers. Pneumatic tools can develop power of over five horsepower and have an operating speed ranging from 3000 to 25,000 rpm. The noise levels produced by typical pneumatic tools are given in Table 7.2.4-1. When a large number of these tools are used, such as in mass production operations, together they produce excessively high noise levels. At the present state-of-the-art, the detailed mechanism of the noise production of pneumatic tools is not well understood. However, the noise created by pneumatic tools is airborne, and the major offender is the air exhaust[68,69]. The frequency of the discrete component of the noise is computed from the blade passage frequency of the motor as:

$$\frac{\text{the speed in rpm x number of vanes (pistons)}}{60}$$

The noise of pneumatic tools may be reduced by:

1. Reduction of the noise at the source,
2. Reduction of the noise radiated by the outer casing, and
3. Reduction of the noise from the exhaust.

At present, little is known about the reduction of the noise at the source, and because of the small area of the casing, radiation from the casing is small. However, studies show that significant reduction of the exhaust noise is possible

Table 7.2.4-1 - Some Representative Pneumatic Tool Noise Levels

		Noise Level dB(C)
Harmful	Pneumatic Chipper (5 Feet)	125
	Three-inch Grinder (3 Feet)	110
Objectionable	Pneumatic Hoist (5 Feet)	93
	Large Pneumatic Drill (1-1/2 feet)	92
Safe	Pneumatic Screw Driver (1-1/2 feet)	80

using mufflers or silencers at the exhaust. Specially designed reactive mufflers of the single, double expansion chamber, and pi-type configuration have been successfully used to obtain substantial reductions of the order of about 20 dB or more. Where the muffler is properly designed, reduction of the order fo 40 dB at the blade passage frequency and 20 dB for the overall noise is possible. The state-of-the-art in muffler design has reached the point where optimization techniques have been applied to the design of reactive mufflers.

(f) Reduction Gear Systems

Geared systems are extremely noisy. Gears consist of assemblies of toothed wheels used for the purpose of torque conversion, speed change or power distribution. The main sources of noise in geared systems are:

1. Mechanical unbalance of the gear assembly,
2. Impact caused by tooth contacts,
3. Friction due to the contact motion of the tooth,
4. Variation of radial forces, and
5. Air and oil pocketing[71,72].

Some of the principles used for reducing noise in gear systems are:

(a) Selection of a suitable type of gear (for instance, a helical gear is quieter than a spur gear, and a worm gear is still quieter, but is restricted to low speeds),

(b) Accuracy of manufacturing (high accuracy in all gear parameters results in quieter gear systems),

(c) Detuning (when the operational frequency of the gear assembly coincides with the natural frequency of the structural members, resonance takes place amplifying the noise; to avoid resonance, the structural members are detuned to other frequencies by either stiffening or mass loading),

(d) Damping (introduced by using gear material of high internal damping),

(e) Vibration isolation, and

(f) Enclosing the gear assembly (with particular attention given to cooling and heat transfer requirements).

Recent studies in gear system noise[73,74] provide interesting guidelines for the purchase of gears, including information as to noise considerations. Figure 7.2.4-1 and Table 7.2.4-2, describe the noise quality classification of geared systems in terms of noise levels and the transmitted horsepower.

Table 7.2.4-2 - Gear Noise Classification
(From References 73 and 74)

CLASS A:	Noise Behavior Cannot be Reliably Obtained Even with High Quality Production Techniques. Additional Sound Absorption, Vibration Damping, Vibration Isolation, Structural Reinforement Are Often Required.
CLASS B:	Result of Extremely High Manufacturing Accuracy and Control.
CLASS C:	High Manufacturing Accuracy.
CLASS D:	Normal Manufacturing Quality Required.
CLASS E:	Gear Drives with High Noise Levels that are Easily Corrected By Increasing the Manufacturing Quality.

Figure 7.2.4-1. Noise Quality Classification for Geared Systems
(From References 73 and 74)

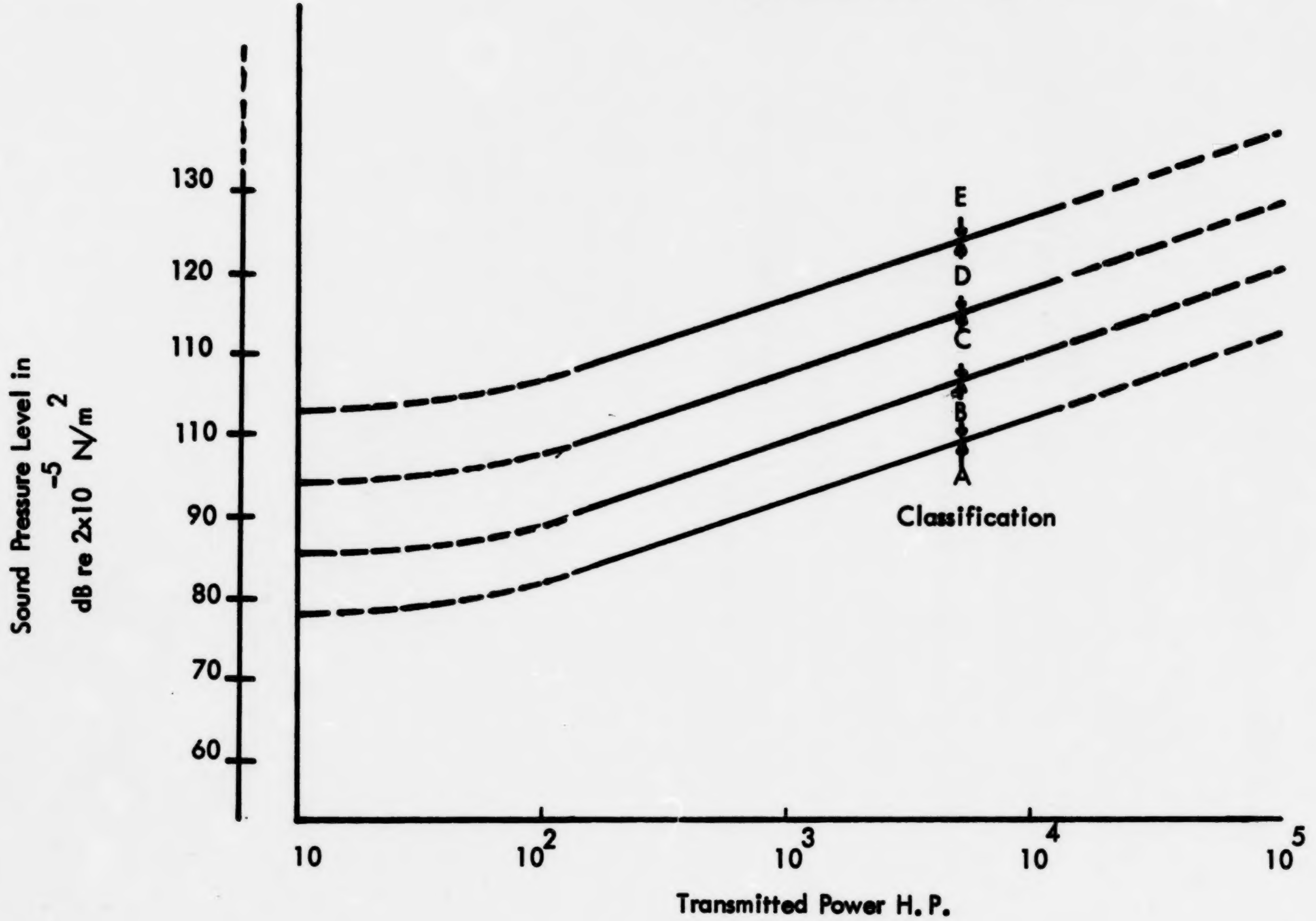

Table 7.2.4-3 provides the noise reductions that are possible by appropriate adjustment of design parameters[74]. Confronted with a noise specification, the gear vendors vary greatly in their sophistication in handling noise problems. Present day trends in making quiet gears take the direction of making precision gear systems and housing them in heavily damped enclosures. Future trends in quieting gear systems lies in using a systems dynamics approach to control noise in the design stage itself[74].

(g) Metal Fabrication (Presses)

Most metal fabricating operations contain one or more of the following: shearing, blanking, punching, and forging. All these, in general, involve the forming or cutting of metal using dies. Operations involving shearing, blanking and punching are performed in punch presses with short duration of the impact forces. Because of the short duration of the impact forces, the noise is strongly dependent on the maximum amplitude of the force. The three basic methods of controlling impact noise are [84,85]:

(a) Control the noise at the source by controlling the duration and magnitude of the impact forces,

(b) Modify the structureborne noise transmission path by vibration isolation, or reduce vibration amplitudes of the housing and foundation at resonance frequencies by the use of appropriate damping, and

Table 7.2.4-3 - Available Noise Reductions for Geared Systems
(From Reference 74)

Design Parameter	Noise Reduction in dB	Remarks
Profile Error	0-5 5-10	Normal Manufacturing Ultra Precision Gears
Profile Roughness	3-7	Full Range of Standard Manufacturing Techniques
Tooth Spacing Error	3-5	
Tooth Alignment Error	0-8	
Speed	$\approx 20 \log \left(\frac{V}{V_o}\right)$	Basic Data V = Speed
Load	$\approx 20 \log \left(\frac{V}{L_o}\right)$	Basic Data, High Loads and Speeds L = Load
Power	$\approx 20 \log \left(\frac{LV}{L_o V_o}\right)$	Basic Data
Pitch	Not Known	Finer, Quieter
Contact Ratio	0-7	Largest Best, But if Small Contact Ratios are Necessary, Use 2.0
Angle of Approach and Recess	Not Known	Approach Forces Higher... Smaller Approach Angle Quieter
Pressure Angle	Not Known	Lower Pressure Angle, Quieter
Helix Angle	2-4	For Changes from Spur to Helix

(continued)

Table 7.2.4-3 (continued)

Design Parameter	Noise Reduction in dB	Remarks
Gear Tooth Backlash	0-14 3-5	If Excessive Backlash If Too Little Backlash
Air Ejection Effects	6-10	5000 fpm or More
Tooth Phasing	Not Known	Not Practical
Planetary System Phasing	5-11	Practical
Gear Housing	6-10	If Resonant
Gear Damping	0-5	If Resonant or Needs Isolation
Bearing	0-4	Adds Damping, Some Types May Stiffen Structure
Bearing Installation	0-2	Can Increase Life and Eliminate Some Frequencies
Lubrication	0-2	Filled Gearbox Quietest, but Can Cause Other Problems

(c) Reduce the levels of the noise in the enclosed space by the use of absorbing structures or baffles.

The nature of the metal working operations precludes the approach described in (a) above. However, methods such as in (b) and (c), have been successfully used to reduce the noise of these types of machines.

In operations involving shearing, blanking and punching using punch presses, the large impact forces exerted by the descending punch on the plate placed upon the die and the shearing action take place simultaneously. If the lower face of the punch is slightly inclined, only a portion of the pate is sheared due to punch geometry. The maximum force needed is reduced, but the total duration of the applied force is increased. This reduction of impact force produces less vibration of the machinery, resulting in a reduction in the overall noise level.

In punching operations, reduction of noise level may be achieved by use of stepped punches, where the punching of successive holes occurs progressively. The characteristics of the material being worked also affect the noise produced.

Harder materials requires greater force, thus producing higher noise levels. Metal working operations involving stainless steel are noisier than those involving cast steel; operations on brass and aluminum are relatively quiet[84]. Poor maintenance often results in higher noise levels. For instance, often there is a second impact occurring in improperly adjusted presses when the flywheel catches up with the moving head an instant after the dies engage. This double impact also subjects bearings, gears, and clutch parts to extra wear, with a subsequent increase in maintenance and cost.

Air ejection systems, which are used to eject small parts or scraps from press dies, are sources of high noise levels. Reduction of noise levels can be obtained by changes in the methods of handling material, either by reducing the jet velocity using a multi-nozzle system, or by streamlining the jet path, or mechanical devices may be used for ejection. Reduction of structureborne noise can be effected by vibration isolation of the machine components from the support structure. Reduction of the noise in the environment surrounding the machine may be obtained by suitably enclosing the machine. Sound absorbent treatment of the ceiling and walls of the room also aid in the reduction of environmental noise.

Reduction of noise at the operator's station may be achieved by suspending sound absorbers in the path of severe noise radiation.

(h) Furnaces and Flares

Combustion is the major source of noise in process plant furnaces. There is as yet no known practical way of quieting a flame releasing millions of BTUs per hour. There are two types of flames for a given heat release: a short bluish intense turbulent flame, and a large brilliant yellowish non-turbulent flame[76]. For thrust controlled flames, noise generally varies as the second power of hear release[79,80,81], and therefore, a load variation (firing rate) of 50 percent would result only in a 3 dB change in noise levels. Reduction of furnace noise can be accomplished by confining the combustion noise within the fire box. In natural draft furnaces, noise reduction may be achieved by completely enclosing the burner registers within highly damped heavy plenum chambers. There must be no radiation path from the burner to the outside of the fire box. It it extimated that noise levels might be reduced to 80 to 85 decibels in front of the fire wall by using this procedure[76]. Another method of noise reduction in natural draft furnaces is using individual shrouded burners provided with integral acoustical baffles which block the transmission path through the individual burner air registers to the inside of the fire box.

Information on the noise levels from more than 25 furnaces show that noise output does not depend significantly on the type of furnace[82], even though the shape of the spectrum may vary. In general, there seems to be about a 10 dB increase in the overall sound power level of furnaces for a ten-fold increase in the heat load[82].

An interesting description of the sources of process plant noise and methods of noise reduction is given in Table 7.2.4-4 reproduced from reference 83.

Flares used to burn excess process plant gases may be sources of community noise. Steam injection systems are used to suppress smoke, luminosity, and combustion-related instabilities. This injection is the major source of noise in the flare[75]. The mechanism of noise production in steam injection systems is the turbulence in the highly sheared mixing region downstream of the jet nozzle. Multiport nozzle system designs, which help in the initial mixing of the steam

Table 7.2.4-4 - Sources of Noise and Methods of Noise Reduction For Process Plant Equipment (From Reference 83)

Equipment	Source of Noise	Method of Noise Reduction
Heaters	Combustion at Burners	Acoustic Plenum*, Seals Around Control Rods and Over Sight Holes
	Inspiration of Premix Air at Burners	Intake Silencer
	Draft Fans	Intake Silencer or Acoustic Plenum
	Ducts	Lagging
Motors	Cooling Air Fan	Intake Silencer, Unidirectional Fan
	Cooling System	Absorbent Duct Liners
	Mechanical and Electrical	Enclosure
Airfin Coolers	Fan	Decrease rpm (Increasing Pitch) Tip and Hub Seals Increase Number of Blades** Decrease Static Pressure Drop** Add More Fin Tubes**
	Speed Changer	Belts in Place of Gears
	Motors	Quiet Motor, Slower Motor
	Fan Shroud	Streamline Air Flow Stiffening and Damping (Reducing Vibration)
Compressors	Discharge Piping and Expansion Joint	Inline Silencer and/or Lagging
	Antisurge Bypass	Use Quiet Valves and Enlarge and Streamline Piping** Lag Valves and Piping Inline Silencers

(continued)

Table 7.2.4-4 (continued)

Equipment	Source of Noise	Method of Reduction
	Intake Piping and Suction Drum	Lagging
	Air Intake	Silencer
	Discharge to Air	Silencer
	Timing Gears (Axial)	Enclosure (or Constrained Damping on Case) Silencers on Intake and Discharge and Lagging
	Speed Changers	Enclosure (or Constrained Damping on Case)
Engines	Exhaust	Silencer (Muffler)
	Air Intake	Silencer
	Cooling Fan	Enclosure Intake or Discharge or Both Use Quieter Fan
Miscellaneous	Turbine Steam Discharge	Silencer
	Air and Steam Vents	Use Quiet Valve Silencer
	Educators	Lagging
	Piping	Limit Velocities Avoid Abrupt Changes in Size and Direction Lagging
	Valves	Limit Pressure Drop and Velocities Limit Mass Flow Use Constant Velocity or Other Quiet Valves Divide Pressure Drop Size Adequately for Total Flow Size for Control Range
	Pumps	Enclosure

*If Oil-Fired, Provide for Drainage of Oil Leaks and Inspection. Omit Liner Where Drips Collect.
**Usually Limited to Replacement Items on New Facilities.

with the aspirated air, are useful in the reduction of the noise in the steam jet[76]. Experiments show that an increase in the initial mixing from 10 percent to 30 percent of the aspirated air with steam results in a reduction of the jet noise by more than 10 dB[77].

Moisture condensation shocks can be developed by sudden precipitation of moisture in a supersaturated state in a steam injection system[78]. For moisture content of as little as two percent, this process of condensation is likely to occur. There is very little information available on the noise produced by the condensation shocks.

Combustion burner instabilities may be initiated by variations in the rate at which gas is supplied and the rate at which it burns. Since this instability may occur only at certain combinations of gas supply rate (i.e., pressure) and gas burning speed (i.e., combustion), it is possible that any gas change (adjustment of the purge-gas system) should disrupt such instabilities[76]. In typical stacks, the low frequency noise due to combustion driven instabilities may cause resonance of the system. This can be reduced by changing the standing wave system in the stacks by use of inside baffles.

(i) Valves

Control (pressure-reducing) valves are the primary cause of piping system noise in process plants. The noise from control valves has been studied by a few investigators[61-66]. An understanding of the basic mechanism of noise generation in control valves would eventually lead to effective design for noise abatement.

The primary mechanism of the noise generation in pressure-reducing valves is eddy-surface interaction, turbulent mixing, and short/turbulence interaction. A discussion of the noise produced by various types of valves is given by Nakano[61]. The variation of sound power (at constant pressure ratio and upstream temperature) has been expressed as a function of mass flow rate raised to some power n, where n is determined experimentally by class of valve.

Empirical methods of predicting valve noise in terms of flow parameters, such as mass flow rate, upstream temperature, molecular weight of the fluid, upstream to downstream pressure ratio, and adiabatic index of the fluid, have been developed. Significant advancement in the design of quiet valves has been made by the application of Lighthill's theory[67] of aerodynamic noise to the noise produced by throttling valves. The most effective way to reduce aerodynamic noise is by reducing the throttling velocity, since the noise level varies as the eighth power of this velocity. Other factors of importance are the effective orifice diameter and the geometry of the valve trim[65].

Acoustical lagging is not an efficient method for reducing noise downstream of a valve since lagging is useful only for noise propagated through the pipe structure and not through the fluid itself.

APPENDIX A

REFERENCES

1. "Occupational Noise Exposure," Federal Register, Vol. 34, N96, Part II, Section 50-204.10. Department of Labor Safety and Health Standards, (May 20, 1969).

2. Sanders, Guy J., "Noise Reduction in Machinery," Noise Control 3 (6), (November 1957), pp. 29-37, 62.

3. Crede, C. E., "Principles of Vibration Control," Chapter 12, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

4. Franken, P. A., "Jet Noise," Chapter 24, Noise Reduction, edited by L. L. Beranek, McGraw-Hill Book Company, (1960).

5. Callaghan, E. E., et al., National Advisory Committee on Aeronautics Technical Note 3590, (1955).

6. Industrial Noise Manual, Chapter 11, p. 121, American Industrial Hygiene Association, Detroit, Michigan, (1966).

7. Fehr, R. D., and Master, D. F., "Electric-Motor and Generator Noise," Chapter 30, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

8. Crede, C. E., "Principles of Vibration Control," and "Vibration Isolation," Chapters 12 and 13, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

9. Fehr, R. D., "The Reduction of Industrial Machine Noise," Proceedings of the Second National Noise Abatement Symposium, Armour Research Foundation, Chicago, Illinois, (1951), p. 99.

10. Mariner, T., and Park, A. D., "Sound Absorbing Screens," Noise Control 2 (5), (September 1956), pp. 22-27, 58.

11. Bishop, D. E., "Use of Partial Enclosures to Reduce Noise in Factories," Noise Control 3 (2), (March 1957), pp. 65-69, 82.

12. Rettinger, M., "Noise Level Reduction of Barriers," Noise Control 3 (5), (September 1957), pp. 50-52.

13. Davis, D. D., "Acoustical Filters and Mufflers," Chapter 21, *Handbook of Noise Control*, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

14. Davis, D. D., Stokes, G. M., Moose, D., and Stevens, G. L., "Theoretical and Experimental Investigation of Mufflers with Comments on Engine Exhaust Muffler Design," NACA Report 1192, (1954).

15. Kessler, F. M., "Application of Conjugate Gradient Optimization Methods to Acoustic Filters Synthesis," Ph.D. Thesis, Department of Electrical Engineering, Rutgers University, New Brunswick, New Jersey, (1971).

16. Hamme, R. N., "Vibration Damping," Chapter 14, *Handbook of Noise Control*, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

17. Emme, J. H., "Composite Materials for Noise and Vibration Control, Sound and Vibration 4 (7), (July 1970), pp. 17-21.

18. Hoover, R. M., "The Sound of Gas Turbine Installations," ASME Paper No. 70-WA/GT-6, presented at the Winter Annual Meeting, New York, (November 29-December 3, 1970).

19. "Gas Turbine Sound and Its Reduction," National Electrical Manufacturers Association Standards,Publication No. SM-33-1964.

20. Eckel, O. C., "Gas Turbine Silencers," ASME Paper No. 63-AHGT-17, presented at the Aviation and Space, Hydraulic and Gas Turbine Conference, Los Angeles, California, (March 1963).

21. McAuliffe, D. R., Morlock, H., and Oran, F. M., "What to Do about Gas-Turbine Noise," ASME Paper No. 63-AHGT-77, presented at the Aviation and Space, Hydraulic and Gas Turbine Conference, Los Angeles, California, (March 1963).

22. Audette, R. R., "Sound Control for Gas Turbine Package Power Plants," presented at the Conference of the American Industrial Hygiene Association, Washington, D.C., (May 1962).

23. Sanders, G. J., "Silencers, Their Design and Application," Sound and Vibration 2 (2), (February 1968), pp. 6-13.

24. Bragg, S. L., and Bridge, R., "Noise from Turbojet Compressors," Journal of the Royal Aeronautical Society 68, (1949), pp. 1-10.

25. Kilpatrick, D. A., and Reid, D. T., "Transonic Compressor Noise - The Effect of Inlet Guide Vane Rotor Spacing," British National Gas Turbine Establishment, Report No. R257, (1964).

26. Bateman, D. A., et al., "Compressor Noise Research," FAA-ADS-31, (1965).

27. Tyler, J. M., and Sofrin, T. G., "Axial Flow Compressor Noise Studies," Transactions of the Society of Automotive Engineers, (1961), pp. 309-332.

28. Sperry, W. C., and Benzakein, M. J., "Experimental Results of Vane/Blade Number Effects on Compressor Noise, American Society of Mechanical Engineers, 13th Annual International Gas Turbine Conference, (March 1968).

29. Lowson, M. V., "Compressor Noise Reduction," presented at the Meeting of the Acoustical Society of America, (November 1966).

30. Benzakein, M. J., and Kazin, S. B., "A Theoretical Prediction of Aerodynamically Generated Noise in Fans and Compressors," presented at the Meeting of the Acoustical Society of America, (November 1968).

31. Benzakein, M. J., and Kazin, S. B., "Fan/Compressor Noise Reduction," American Society of Mechanical Engineers Paper No. 69-GT-9, (March 1969).

32. Benzakein, M. J., "A Study of Fan/Compressor Noise Generation," National Aeronautics and Space Administration Special Report - 207.

33. Benzakein, M. J., and Morgan, W. R., "Analytical Prediction of Fan/Compressor Noise," American Society of Mechanical Engineers Paper No. 69-WA/GT-10, (1969).

34. Shanland, I. J., "Sources of Noise in Axial Flow Fans," Journal of Sound and Vibration 1 (3), (1964), pp. 302-322.

35. Chestnut, D., "Noise Reduction by Means of Inlet Guide Vane Choking in an Axial Flow Compressor," National Aeronautics and Space Administration Technical Note D-4682, (July 1968).

36. Morfey, C. L., and Dawson, H., "Axial Compressor Noise: Some Results from Aero-Engine Research," presented at the Gas Turbine Conference of the American Society of Mechanical Engineers, Zurich, (March 1966).

37. Benzakein, M. J., and Hocheiser, R. M., "Some Results of Fan/Compressor Noise Research," American Society of Mechanical Engineers Paper No. 70-WA/GT-12, (1970).

38. Lowson, M. V., "Theoretical Studies of Compressor Noise," Wyle Laboratories, Research Staff Report WR68-15, (August 1968). (A bibliography on compressor noise is included in this report.)

39. Webb, H. E., "Compressor, Household-Refrigerator and Room Air-Conditioner Noise," Chapter 28, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

40. Blazier, W. E., Jr., "Noise from Large Centrifugal Compressors,"Proceedings of the Purdue University Noise Control Conference, R. W. Herrick Laboratories, (July 1971), pp. 83-88.

41. "The First Quiet Portable Compressor," Sound and Vibration 3 (5), (May 1969), pp. 6-8.

42. Madison, R. D., and Wells, R. J., "Fan Noise," Chapter 25, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

43. Allen, C. H., "Noise Control in Ventilation Systems," Chapter 21, Noise Reduction, edited by L. L. Beranek, McGraw-Hill Book Company, (1960).

44. Beranek, L. L., Reynolds, J. L., and Wilson, K. E., "Apparatus and Procedures for Predicting Ventilation System Noise," JASA 25, (1953), pp. 313-321.

45. Peistrup, C. F., and Wesler, J. E., "Noise of Ventilating Fans," JASA 25, (1953), pp. 322-326.

46. Beranek, L. L., Kamperman, G. W., and Allen, C., "Noise of Centrifugal Fans," JASA 27, (1955), pp. 217-219.

47. Goldman, R. B., and Maling, G. C., "Noise from Centrifugal Fans," Noise Control 1, (1955), pp. 26-29.

48. Chipps, G. E., "Noise Produced by a Centrifugal Ventilating Fan," M.E. Thesis, McGill University, (1956).

49. Huebner, G. H., "Noise of Centrifugal Fans and Rotating Cylinders," Transactions of the ASHRAF 60, (1963), pp. 181-189.

50. Maroti, L. A., and Pradhan, A. V., "Noise Generation Characteristics of High Speed Centrifugal Fans," ASME Paper No. 69-WA/FE-9 presented at the Winter Annual Meeting, Los Angeles, California, (November 1969).

51. Chanaud, R. C., "Aerodynamic Sound from Centrifugal Fan Rotors," JASA 37 (6), (1965), pp. 968-974.

52. Embleton, T. F. W., "Experimental Study of Noise Reduction in Centrifugal Blowers," JASA 35 (5), (1963), pp. 700-705.

53. Sanders, G. J., "Noise Control in Air Handling Systems," Sound and Vibration 1 (2), (February 1967), pp. 8-18.

54. Sanders, G. J., "Silencers, Their Design and Application," Sound and Vibration 2 (2), (February 1968), pp. 6-13.

55. Hoover, R. M., and Wood, C. O., "Noise Control for Induced Draft Fans," Sound and Vibration 4 (4), (April 1970), pp. 20-24.

56. Shaw, A. M., "Make Your Pump Shut Up," Reprint No. 459, Worthington Corporation, Harrison, New Jersey.

57. Evans, L. M., "How to Control Centrifugal Pump Noise," Reprint No. 894, Worthington Corporation, Harrison, New Jersey.

58. Meyerson, N. L., "Noise Reduction in Pumps and Pump Systems," Noise Control 3 (2), (March 1957), pp. 27-32, 91.

59. Szerlag, S. F., "Quieting Hydraulic Components," Proceedings of the Purdue Noise Control Conference, Lafayette, Indiana, (July 1971).

60. Callaway, D. B., "Noise in Water and Steam Systems," Chapter 26, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

61. Nakano, A., "Characteristics of Noise Emitted by Valves," Paper No. F-172, The 6th International Congress on Acoustics, Japan, (August 21-28,1968), p. 169.

62. Allen, E. E., "Prediction and Abatement of Control Valve Noise," Paper No. 69-535, Annual Conference of the Instrument Society of America, (1969).

63. Ribner, H. S., "Acoustic Energy Flux from Shock-Turbulence Interaction," UTIAS Technical Note No. 108AFOSR 67-0221, (July 1971).

64. Seebold, J. G., "Process Plant Noise Control at the Design Engineering Stage," ASME Paper No. 70-PET-11, presented at the Petroleum Mechanical Engineering and Pressure Vessels and Piping Conference, Denver,Colorado, (September 1970).

65. Bauman, H. D., "On the Prediction of Aerodynamically Created Sound Pressure Level of Control Valves," ASME Paper No. WA/FE-28, presented at the Winter Annual Meeting, New York, New York, (November 29-December 3, 1970).

66. Schuder, C. B., "Control Valve Noise - Prediction and Abatement," Proceedings of the Purdue Noise Control Conference, Purdue University, Lafayette, Indiana, (July 1971), pp. 89-93.

67. Lighthill, M. J., "On the Sound Generated Aerodynamically, Part I," Proceedings of the Royal Society, London, (1952), and "Part II," Proceedings of the Royal Society, London, (1954).

68. Chaffee, W. C., "Reduction of Noise in Industrial Pneumatic Tools, Noise Control 1 (2), (March 1955), pp. 16-18, 67.

69. Potschke, H., "Noise Reduction," Hydraulic Pneumatic Power, (August 1966), pp. 490-492. (Translated from German original published in "Oelhydraulik und Pneumatik.")

70. Kessler, F. M., and Puri, N. N., "Acoustic Filter Systhesis Using Conjugate Gradient Search Techniques," JASA 49 (5), (May 1971), pp. 1357-1361.

71. Moeller, Kurt G. F., "Gear Noise Reduction," Noise Control 1 (2), (March 1955), pp. 11-15, 61.

72. Moeller, Kurt G. F., "Gear Noise," Chapter 23, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

73. Opitz, H. C. H., Zumbrouch, H., and Timmers, J., "Siriesunteruchungen des Geraüschverhaltens Moderner Hocklastgelriebe," Industrie-Anzeiger, Essen 87 Jg. Nr. 96, (November 1965).

74. Mitchell, I. D., "Gear Noise: The Purchaser's and Manufacturers' Views," Proceedings of the Purdue Noise Control Conference, Lafayette, Indiana, (July 1971), pp. 94-106.

75. Guide for Pressure Relief and Depressuring Systems, American Petroleum Institute, Division of Refining, New York, API RP 521, 1st ed., (September 1969), pp. 52-55.

76. Seebold, J. G., "Process Plant Noise Control at the Design Engineering Stage," ASME Paper No. 70-PET-11, presented at the Petroleum Mechanical Engineering and Pressure Vessels and Piping Conference, Denver, Colorado, (September 1970).

77. Seebold, J. G., and Hersh, A. S., "Refinery Flare Steam Injectors Redesigned for Noise Control," ASME Paper No. 70-WA/PET-4, presented at the Winter Annual Meeting, New York, (November 29-December 3, 1970).

78. Shapiro, A. H., The Dynamics and Thermodynamics of Compressible Fluid Flow, Ronald Press, New York, (1953), pp. 203-205.

79. Smith, T. J. B., and Kilham, J. K., "Noise Generation by Open Turbulent Flames," JASA 35 (5), (1963), p. 715.

80. Smithson, R. N., and Foster, P. J., "Combustion Noise from a Meker Burner," Combustion and Flame 9, (December 1965), p. 426.

81. Giammar, G. D., and Putnam, A. A., "Combustion Roar of Turbulent Diffusion Flames," Journal of Engineering for Power, Trans. ASME, Series A, 92 (2), (July 1970), pp. 157-165.

82. Davies, R. J., "Environmental Noise Control in Petroleum Industry," Lecture presented at Concave Technical Meeting on Environmental Noise Control held in The Hague, (20th March, 1968).

83. Judd, S. H., "Noise Abatement in Process Plants," Chemical Engineering, (January 1971), pp. 139-145.

84. Crede, C. E., "Control of Impact Noise," The Acoustical Spectrum, The University of Michigan Press, Ann Arbor, Michigan, (February 1952), pp. 117-126.

85. Crede, C. E., "Principles of Vibration Control," Chapter 12, Handbook of Noise Control, edited by C. M. Harris, McGraw-Hill Book Company, (1957).

APPENDIX B

SELECTED BIBLIOGRAPHY

1. Anderson, A. B. C., "Structure and Velocity of the Periodic Vortex-ring Flow Pattern of a Primary Pfeifenton (pipe tone) Jet," Journal of the Acoustical Society of America 27 (6), (1955), pp. 1048-1053.

2. Anderton, D., et al., "Origins of Reciprocating Engine Noise - Its Characteristics, Prediction, and Control," ASME Paper 70-WA/DGP-3, Winter Annual Meeting of the American Society of Mechanical Engineers, New York, New York, (November 29-December 3, 1970).

3. Banhister, R. L., and Thomas, R. J., "An Experimental Mechanical Impedance Technique," Sound and Vibration 2 (3), (March 1968), pp. 10-16.

4. Barry, G., "Measurement and Analysis of Noise in Factories," Journal of the Institute of Plant Engineers 8 (1), (1962), pp. 3-14.

5. Bonvallet, G. L., "Retaining High Sound-Transmission Loss in Industrial Products," Noise Control 3 (2), (March 1957), pp. 61-64, 92.

6. Boratynski, N., "Plant Planning for Noise Control," Noise Control 2 (4), (July 1956), pp. 37-46, 95.

7. Botsford, J. H., "Compressed Air Exhaust Mufflers," American Industrial Hygiene Association Quarterly 15, (1954), p. 57.

8. Botsford, J. H., "Current Trends in Hearing Damage Risk Criteria," Sound and Vibration 4 (4), (April 1970), pp. 16-19.

9. Bradgley, R. H., "Mechanical Aspects of Gear Induced Noise in Complete Power Train Systems," ASME Paper No. 70-WA/DGP-1, Winter Annual Meeting of the American Society of Mechanical Engineers, (November 29-December 3, 1970).

10. Bragg, S. L., and Bridge, R., "Noise from Turbojet Compressors," Journal of the Royal Aeronautics Society 68 (637), (January 1964).

11. Broadbent, D., and Little, E., "Effects of Noise Reduction in a Work Situation," Occupational Psychology 34, (1960), pp. 133-140.

12. Brozek, B., "Noise in High Speed Motors," Machine Design, (March 5, 1970), pp. 123-127.

13. Callaway, P. B., "Reducing Noise in Machines," Machine Design 23, (1951), p. 122.

14. Caudra, E., and Beland, R. D., "Rationale for the Comprehensive Control of Urban Noise," Proceedings of the Institute of Environmental Sciences, (1970), pp. 236-243.

15. Chanaud, R. C., and Powell, A., "Some Experiments Concerning the Hole and Ring Tone," Journal of the Acoustical Society of America 37 (5), (1965), pp. 902-911.

16. Charson, G. L., "Will You Reduce the Noise on Your Design for the 1970's," Hydraulics and Pneumatics 22 (11), (November 1969), pp. 75-80.

17. Chestnut, D., "Jet Engine Inlet Noise Control," Sound and Vibration 2 (12), (December 1968), pp. 10-14.

18. Christman, R. P., Herbert, H. J., and Bales, R. E., "Sound Pressure Levels in the Wood Products Industry," Noise Control 2 (5), (September 1956), pp. 33-38, 72.

19. Cirlett, E. N., Mercombe, V. J., and Chandra, B., "Shielding Factory Noise by Work-In-Progress Storage," Applied Agronomics, (March 1970), pp. 73-78.

20. Clark, W., and Pietrasanta, A., "Community and Industrial Noise," American Journal of Public Health 51,(1961), pp. 1329-1337.

21. Cohen, J. A., and Jones, H. H., "'Sociocusis' Hearing Loss from Non-occupational Noise Exposure," Sound and Vibration 4 (11), (November 1970), pp. 12-20.

22. Cox, J. R., "Enclosure for a Can Davider," American Industrial Hygiene Association Quarterly 15, (1954), p. 40.

23. Crawford, R., "Noise of Rotating Spindles and Bobbins in a Textile Machine," Journal of Sound and Vibration 5 (2), (March 1967), pp. 317-329.

24. Crouch, H. W., "Controlling the Noise from Panel Press Areas," American Industrial Hygiene Association Quarterly 15, (1954), p. 38.

25. Crouch, H. W., "Noise Reduction by Enclosing Jordan Shredding Machine," American Industrial Hygiene Association Quarterly 15, (1954), p. 40.

26. Cudworth, A., "Field and Laboratory Examples of Industrial Noise Control," Noise Control 5 (1), (1959), pp. 39-43, 73.

27. Damewood, G., Sparks, C. R., Hanchett, M. T., and Brown, M. E., "Blow-off Noise Suppression and Regulator Valve Noise Generation," Noise Abatement at Gas Pipeline Installations, Vol. III, American Gas Association, Inc., (November 1961).

28. Dyer, I., "Noise Attenuation of Dissipative Mufflers," Noise Control 2 (3), (May 1956), pp. 56-57, 78-79.

29. Edwards, G., "Design for a Quieter Future; How to Muffle the Noisy Diesel," Design Engineering, Materials, and Components, (15th October 1970), pp. 49-51.

30. Gardiner, R. E., Nordberg, K. S., and Silsbee, D. L., "Acoustical Foams for Sound Absorption Applications," Sound and Vibration 4 (7), (July 1970), pp. 12-16.

31. Geiger, P. H., and Hamme, R. N., "Methods for Reducing the Noise of Industrial Machines," Proceedings of the Third Annual National Noise Abatement Symposium, (1952), p. 19.

32. Granier, M. G., "Industrial Noise and the Neighborhood," Silence, (October/December 1967), pp. 9-11, (in French).

33. Griffiths, J. W. R., "The Spectrum of Compressor Noise of a Jet Engine," Journal of Sound and Vibration 1 (2), (1964), pp. 127-140.

34. Hahn, R. S., "Design of Lanchaster Damper for Elimination," Transactions of the ASME 75, (1951), p. 331.

35. Hahn, R. S., "Metal-Cutting Chatter and Its Elimination," Transactions of the ASME 75, (1953), p. 1073.

36. Hardy, H. C., "Engineering and Zoning Regulations of Outdoor Industrial Noise," Noise Control 3 (3), (May 1957), pp. 32-38.

37. Hetherington, R., "Compressor Noise Generated by Fluctuating Lift Resulting from Rotor-Stator Interactions," American Institute of Aeronautics and Astronautics Journal 1 (2), (February 1963), pp. 473-474.

38. Hoover, R. M., and Williams, "Noise Control for Reciprocating Compressors," Heating, Piping and Air Conditioning 34 (11), (November 1963).

39. Hulse, B. T., and Large, J. B., "The Mechanism of Noise Generation in a Compressor Model," ASME Paper 66-GT/N-42, (April 1966), pp. 191-198.

40. Ingard, Uno, "Attenuation and Regeneration of Sound in Ducts and Jet Diffusers," Journal of the Acoustical Society of America 33 (9), (September 1959), pp. 1202-1235.

41. Jackson, R. S., "Some Aspects of the Performance of Acoustic Hoods," Journal of Sound and Vibration 3 (1), (January 1966), pp. 82-94.

42. Johnson, C. N., "Fractional Horsepower Rotary Vane Refrigerant Compressor Sound Source Investigation," Purdue University Ph.D. Thesis, (August 1969).

43. Junger, M. C., "Sound Transmission Through an Elastic Enclosure Acoustically Closely Coupled to a Noise Source," ASME Paper 70-WA/DE-12, Winter Annual Meeting of the American Society of Mechanical Engineers, New York, New York, (November 29-December 3, 1970).

44. Kemp, N. H., and Sears, W. R., "Aerodynamic Interference Between Moving Blade Rows," Journal of the Royal Aeronautical Sciences 20 (7), (September 1953), pp. 585-598.

45. King, A. J., "Setting Standards for Machine Noise," Engineering 198 (5176), (1964), pp. 93-95.

46. Lane, R. N., "Silencer for Cat Cracker," Noise Control 3 (6), (November 1957), pp. 48-50.

47. Lazarus, M., "How To Approximate Transmissibility Curves," Sound and Vibration 3 (6), (June 1969), pp. 25-26.

48. Lo, N. K., and Rembold, U., "Development of Double Lobed Cylinder for Rotary Vane Compressors," Proceedings of Semi-Annual ASHRAE Meeting, Detroit, Michigan, (February 1967).

49. Lowe, R. T., and Crede, C. E., "Recent Developments and Future Trends in Vibration Isolation," Noise Control 3 (6), (November 1957), pp. 21-28, 70.

50. Lowery, R. L., "Compressor Valve Noise and Vibration Studies," Purdue University Ph.D. Thesis, (June 1969).

51. Maekawa, Z., "Noise Reduction of Screens," Applied Acoustics 1 (3), (July 1968), pp. 157-173.

52. Marsh, J. A., "The Airborne Sound Insulation of Glass," Paper presented at the British Acoustical Society Meeting at Newcastle-upon-Tyne, (1970).

53. Mattei, J., "Planning for Noise Control of New Industrial Plant," Journal of Sound and Vibration 4 (2), (September 1966), pp. 249-255.

54. Meyerson, N. L., "Noise Reduction in Pumps and Pump Systems," Noise Control 3 (2), (March 1957), pp. 27-32, 91.

55. Mitchell, L. D., and Lynch, G. A., "Origins of Noise," Machine Design, (May 1, 1969), p. 174.

56. Mitchell, L. D., and Lynch, G. A., "Progress in Noise Analysis," DuPont Innovations 1, (1969), pp. 9-11.

57. Ogden, J., "Typical Examples of Noise Reduction in General Motors Corporation," Transactions of the Annual Meeting of the Industrial Hygiene Foundation, Pittsburgh, (1952).

58. Pietrasanta, A. C., "Fundamentals of Noise Control, "Noise Control 1 (1), (1955), pp. 10-18.

59. Pish, R. H., and Hall, R. W., "Noise Reduction Techniques as They Apply to Engine-Generator Design and Treatment," SAE Technical Paper 690755, Presented at the Natural Power Plant Meeting, Cleveland, Ohio, (October 27-29, 1969).

60. Raes, A. C., "They Are Doing Something About Noise in Reducing Valve Noise in Sugar Refinery," Noise Control 2 (6), (November 1956), pp. 55-56, 64.

61. Rees, W. M., "Acoustical Engineering Principles for Noise Reduction," Noise Control 3 (2), (March 1957), pp. 59-60, 84.

62. Rice, C. G., and Walker, J. G., "Subjective Assessment of Noise Spectra from Large Industrial Sites," Applied Acoustics 1 (3), (July 1968), pp. 189-203.

63. Robinson, I. F. S., and Shirley, M. B., "Noise Problems in Large Refinery," Proceedings of the 6th World Petroleum Congress, Section VII, (June 1959), pp. 309-326.

64. Rosen, M. W., "Noises of Two Spur-Gear Transmissions," Noise Control 7 (6), (November-December 1961), pp. 11-19.

65. Route, W. D., "Gear Design for Noise Reduction," SAE Technical Paper 208E, (July 1, 1960).

66. Sacerdote, G., "Statistical Measurements of Factory Noise," Noise Control 5 (6), (1953), pp. 29-31, 53.

67. Sallee, E., and Guy, A., "Punch Press Noise Control," American Industrial Hygiene Association Journal 19 (5), (1958), pp. 409-412.

68. Schaudinischky, L. H., and Schwartz, S., "On the Acoustic Problems of Cooling Towers," Applied Acoustics 1 (4), (October 1968), pp. 309-322, (in German).

69. Seiner, J. M., "The Design and Development of a Spinning Mode Synthesizer," The Pennsylvania State University, M. S. Thesis, (September 1969).

70. Slout, N. P., "Noise Characteristics of Textile Machinery," The Textile Institute and Industry, (March 1970), pp. 61-64.

71. Snow, W. B., "Engineering Solutions to Industrial Noise Problems," Noise Control 2 (4), (July 1956), pp. 72-76, 92.

72. Sparks, C. R., "Design of High Pressure Blow-off Silencers," Journal of the Acoustical Society of America 34 (5), (May 1962), pp. 602-608.

73. Szerlag, S. F., "Quieting Hydraulic Components," Proceedings of the Purdue Noise Control Conference, Lafayette, Indiana, (July 14-16, 1971), pp. 495-499.

74. Tarn'oczy, "Vibration of Metal Plates Covered with Vibration Damping Layers," Journal of Sound and Vibration 11 (3), (March 1970), pp. 299-307.

75. Tseo, G. G., "Estimating the Performance of Wall Structures Used for Controlling Noise," Proceedings of the Purdue Noise Control Conference, Lafayette, Indiana, (July 14-16, 1971), pp. 115-122.

76. Walker, C. W. E., "The Powell River Suction Roll Silencer," Noise Control 2 (5), (September 1956), pp. 39-45, 58.

77. Washburn, E. S., "Legal Developments in Industrial Noise," Noise Control 2 (4), (July 1956), pp. 68-70.

78. Wells, R. J., "Enclosures for Noise Reduction in the Factory," American Industrial Hygiene Association Quarterly 15, (1954), p. 59.

79. Wendt, E. H., "Techniques of Noise Control for Public Utilities," Noise Control 3 (5), (September 1957), pp. 37-40, 62.

80. Young, R., "Some Noise Control Methods Used in Industrial Operations," American Industrial Hygiene Association Journal 19 (6), (December 1958), pp. 520-527.

81. Zallen, D. M., "Analysis of Flow Changes at the Compressor Face Resulting from a Blast Wave Impinging the Engine Inlet of a Moving Aircraft," FZA-12-075, Fort Worth Division of General Dynamics, Fort Worth, Texas, (April 1969).

APPENDIX C

STANDARDS AND SPECIFICATIONS

1. CAGI-PNEUROP Test Code for the Measurement of Sound from Pneumatic Equipment. Compressed Air and Gas Institute, New York, New York, 1969. (ANSI S5.1 - 1971)

2. ASHRAE Standard 36-62: Measurement of Sound Power Radiated from Heating, Refrigerating and Air Conditioning Equipment. American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York, New York, February 1962.

3. ARI Standard 443-70: Sound Rating of Room Fan-Coil Air Conditioners. Air Conditioning and Refrigeration Institute, Washington, D. C., 1970.

4. ARI Standard 270-67: Sound Rating of Outdoor Unitary Equipment. Air Conditioning and Refrigeration Institute, Washington, D. C., 1967.

5. ARI Standard 446-68: Sound Rating of Room Air-Induction Units. Air Conditioning and Refrigeration Institute, Washington, D. C., 1968.

6. ARI Standard 275-69: Application of Sound Rated Outdoor Unitary Equipment. Air Conditioning and Refrigeration Institute, Washington, D. C., 1969.

7. ADC Test Code 1062 R2-C.14.0: Test of Sound Measurement. Air Diffusion Council, Chicago, Illinois, 1966.

8. ADC Standard AD-63: Measurement of Room to Room Sound Transmission Through Plenum Air Systems. Air Diffusion Council, Chicago, Illinois, 1963.

9. IEEE Standard 85: Test Procedure for Air Borne Noise Measurements on Rotating Electric Machinery. The Institute of Electrical and Electronics Engineers, New York, New York, February 1965.

10. NEMA Standard TR-27-5.09: Audible Sound Level Tests for Commercial, Institutional, and Industrial Dry Type Transformers. National Electrical Manufacturers Association, New York, New York, 1965.

11. NEMA Standard ST 1-4-2.7: Audible Sound Level Test for Specialty Transformers. National Electrical Manufacturers Association, New York, New York, 1961.

12. NEMA Standard SM 21-5: Sound Pressure Levels for Mechanical Drive Steam Turbines, Multi-Stage. National Electrical Manufacturers Association, New York, New York, 1970.

13. NEMA Standard SM 22-5: Sound Pressure Levels for Mechanical Drive Steam Turbines, Single Stage. National Electrical Manufacturers Association, New York, New York, 1970.

14. NFPA Standard T 3.9.70.12: Method of Measuring Sound Generated by Hydraulic Fluid Power Pumps. National Fluid Power Association, Thiensville, Wisconsin, 1970.

15. AGMA 295.03: Specification for Measurement of Sound on High Speed Helical and Herringbone Gear Units. American Gear Manufacturers Association, Washington, D. C., December 1968.

16. IEEE Standard No. 85: Test Procedure for Airborne Noise Measurements on Rotating Electric Machinery. The Institute of Electrical and Electronics Engineers, New York, New York, February 1965.

17. AMCA Standard 300-67: Test Code for Sound Rating Air Moving Devices. Air Moving and Conditioning Association, Inc., Arlington Heights, Illinois, January 1967.

18. AMCA Rating Procedure 301-65: Standard Method of Publishing Sound Ratings. Air Moving and Conditioning Association, Inc., Arlington Heights, Illinois, February 1965.

19. AMCA Certification 311-67: Certified Sound Rating Program for Air Moving Devices. Air Moving and Conditioning Association, Inc., Arlington Heights, Illinois, 1967.

20. NMTBA: Noise Measurement Techniques. The National Machine Tool Builders Association, Washington, D. C., June 1970.

APPENDIX D

INSTRUMENTATION, FLOW DIAGRAMS, and COMPUTER PRINTOUTS

The instrumentation systems used for this project are tabulated in this Appendix. The manufacturer, type, model number, and serial number are presented for each unit. Most instrumentation systems (transducer through amplifier, record and playback) contain non-linearities in frequency; that is the system frequency response is not flat in the frequency range of interest. These non-linearities can be compensated for by using a General Radio Real-Time Analyzer. The necessary corrections are applied to each one-third octave band from 25 hertz to 8000 hertz using the GR multifilter.

This Appendix also contains the flow diagrams describing the computer programs used for the various statistical computations to which the data was subjected. Examples of the computer printout, in the form of statistical values, percentile values, and noise level (A-weighted) histogram are also presented.

An instrumentation list, discussed above, of equipment used for this program is presented in this Appendix as Table D-1. Table D-2 lists the attenuater corrections required because of windscreen, microphone, random incidence corrector, sound level meter, and Nagra/Crown tape recorder deviations from a flat frequency response.

Flow charts describing the statistical data analysis are presented as Figure D-1, while the computer output format is shown as Figure D-2. The noise level histograms were accomplished using the PDP-8/I computer. An example of this histogram format is presented as Figure D-3.

Table D-1 - Instrumentation List

Pistonphone Calibrator

Bruel & Kjaer Model 4220, Serial Number 96912
Bruel & Kjaer Model 4230, Serial Number 282298

Capacitor Microphone Cartridge

Bruel & Kjaer Model 4145, Serial Number 259598
Bruel & Kjaer Model 4145, Serial Number 270841
Bruel & Kjaer Model 4148, Serial Number 260219

Windscreen

Bruel & Kjaer Model UA-0207

Random Incidence Corrector

Bruel & Kjaer Model UA-0055

Extension Cable

Bruel & Kjaer Model AO-0028

Precision Sound Level Meter

Bruel & Kjaer Model 2203, Serial Number 96843
Bruel & Kjaer Model 2204, Serial Number 285686
Bruel & Kjaer Model 2206, Serial Number 253198

Octave Filter Set

Bruel & Kjaer Model 1613, Serial Number 91513
Bruel & Kjaer Model 1613, Serial Number 257209

Magnetic Tape Recorder

Kudelski Nagra IVB, Serial Number 1349903

Table D-2 - Attenuation Corrections

Frequency	Nagra IV Crown 800 Scotch 175 7.5 ips	B&K 4145 Microphone	Random Incidence Corrector	Windscreen	Total Correction	Multifilter Settings
25	+3	0	0	0	+3	-3
31.5	+2.7				+2.7	-3
40	+.7				+.7	-1
50	+.8				+.8	-1
63	+3				+3	-3
80	+1				+1	-1
100	+1				+1	-1
125	0				0	0
160	+1				+1	-1
200	+1				+1	-1
250	+1				+1	-1
315	+.6				+.6	-1
400	+.6				+.6	-1
500	+.5				+.5	-1
630	+.3				+.3	0
800	+.2	↓	↓		+.2	0
1000	0	-.1	+.1	↓	0	0
1250	0	-.3	+.1	+.1	-.1	0
1600	0	-.6	+.2	+.2	-.2	0
2000	0	-1	+.2	+.3	-.5	+1
2500	0	-1.5	+.3	+.5	-.7	+1
3150	0	-2.2	+.4	+.4	-1.4	+1
4000	0	-3.3	+.9	+.1	-2.3	+2
5000	-1	-4.4	+1.7	-.4	-4.1	+4
6300	-1	-6.7	+3.0	-.7	-5.4	+5
8000	-1.2	-7.5	+4.0	-.5	-5.2	+5
10,000	-3	-9.3	+6.4	-1.6	-7.5	+8
12,500	-6	-10.5	+6.0	-1.2	-11.7	+12
16,000	-14	-12.5	-2			
20,000						

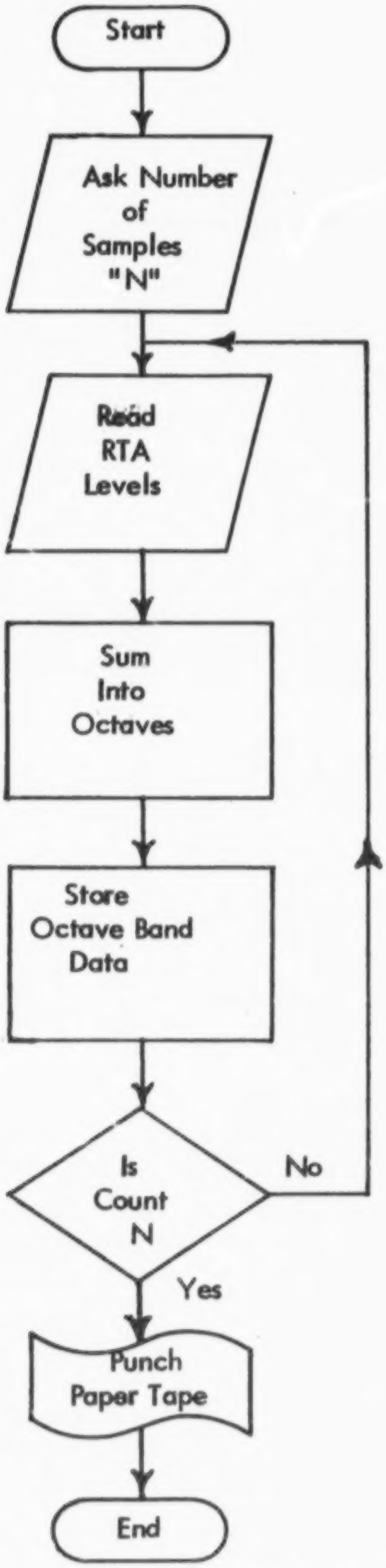
Start
Ask Number of Samples "N"
Read RTA Levels
Sum Into Octaves
Store Octave Band Data
Is Count N
No
Yes
Punch Paper Tape
End

Figure D-1a. Paper Tape Generation Program for Statistical Analysis

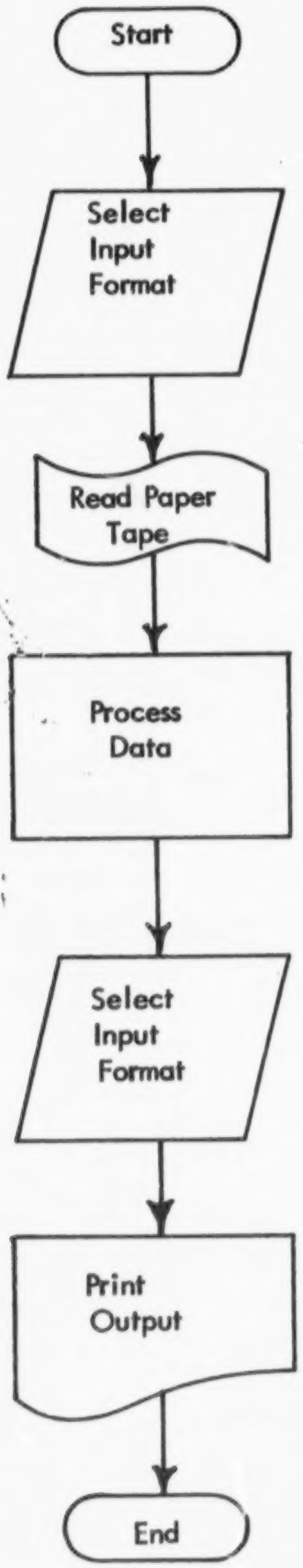
Start
Select Input Format
Read Paper Tape
Process Data
Select Input Format
Print Output
End

Figure D-1b. Statistical Analysis Program

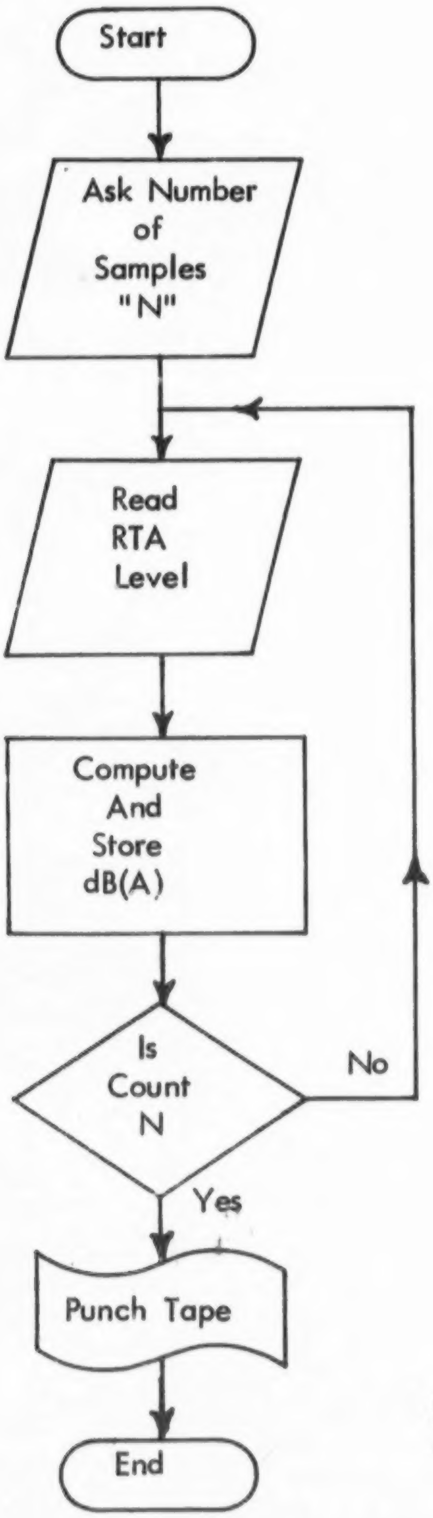
Start
Ask Number of Samples "N"
Read RTA Level
Compute And Store dB(A)
Is Count N
No
Yes
Punch Tape
End

Figure D-1c. Paper Tape Generation for Noise Level (A-weighted) Histogram.

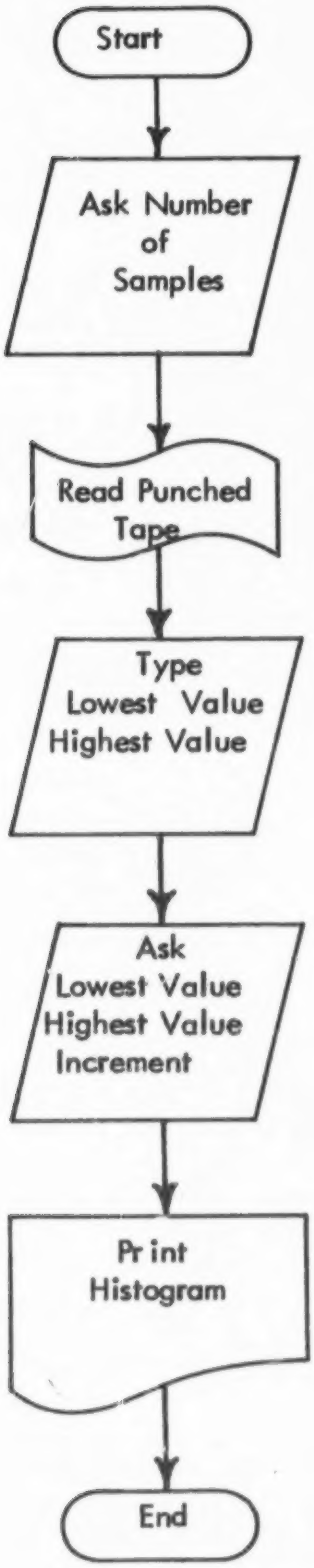
Start
Ask Number of Samples
Read Punched Tape
Type Lowest Value Highest Value
Ask Lowest Value Highest Value Increment
Print Histogram
End

Figure D-1d. Noise Level (A-weighted) Histogram

```
                        ** STATISTICAL VALUES **

                                OCTAVE BAND
           *   31.5     63    125    250    500   1000   2000   4000   8000
************************************************************************
MAX SPL    *     64     67     64     57     57     53     50     43     44
MIN SPL    *     57     59     53     48     42     42     40     38     39
NO.OF OCC.*     100    100    100    100    100    100    100    100    100
MEAN       *   59.8   62.7   60.2   52.9   51.8   48.1   46.0   40.2   41.6
MEDIAN     *     60     62     60     53     52     48     46     40     41
STD. DEV.  *    1.4    1.5    1.5    1.6    1.7    1.5    1.0    0.9    1.1



                             ** PERCENTILE VALUES **

 OCTAVE       L       L       L
  BAND       90      50      10
******************************
   31.5 *    58      60      51
   63.0 *    61      62      55
  125.0 *    58      60      52
  250.0 *    51      53      55
  500.0 *    50      52      54
 1000.0 *    47      46      50
 2000.0 *    45      46      47
 4000.0 *    39      40      41
 8000.0 *    40      41      43
 LINEAR *    64      66      58
   A-WT *    52      54      56
   B-WT *    58      59      52
   C-WT *    64      65      57
   D-WT *    60      62      54

   SIL  *    47      49      50


************************************************************************
```

Figure D-2. Sample Statistical Analysis Computer Printout

```
NUMBER OF SAMPLES:50
::::::::::::::::::::::::::::::::::::::::::::::::::
     LOWEST VALUE  44.32
     HIGHEST VALUE  49.60
TYPE IN INTEGER VALUES FOR THE LOWEST VALUE, HIGHEST
VALUE, AND INCREMENT
LOWEST VALUE:40
HIGHEST VALUE:50
INCREMENT:1
```

REEL 01 RUN 006 ENG AJD DATE 6-22-71 Location 5 Night Glass Manufacturi
Plant

```
  40
  41
  42
  43
  44 **
  45 *************
  46 *****************
  47 ***********
  48 *****
  49 **
  50
    -------------------------------------------------
                        NUMBER OF OCCURRENCES
```

* Figure D-3. Sample Noise Level (A-weighted) Histogram Printout